THE EASTERN PORTION OF MOUNT McKINLEY NATIONAL PARK

By Stephen R. Capps

ABSTRACT

The eastern portion of Mount McKinley National Park includes areas that have been studied by a number of geologists during the last 30 years, and several reports on portions of it have already been published. The heretofore unpublished results of two seasons of field work by S. R. Capps, together with all other available information, are here compiled into a single report covering that portion of the park that lies east of Muldrow Glacier. Geologic formations ranging in age from pre-Cambrian to Recent and including Paleozoic, Mesozoic, Tertiary, and Quaternary deposits are described, and their character, thickness, age, and stratigraphic and structural relations are discussed.

The eastern portion of Mount McKinley Park is not generally well mineralized, only a small amount of placer gold has been recovered from it, and metallic lodes of promise have been found at only a few localities. Those of the Mount Eielson district are described by Moffit in an accompanying paper. In the basin of the West Fork of the Chulitna River lodes containing gold, copper, antimony, and arsenic have been prospected from time to time, but most of them have now been abandoned. A few groups of claims on gold lodes are still held and show promise of eventual development. Lignite or subbituminous coal occurs at many localities but is at present of value only for local uses.

INTRODUCTION

The region here considered includes the portion of Mount McKinley National Park that lies east of meridian 151° 30′ and a narrow belt of country contiguous to the park boundary. It extends from longitude 147° 30′ to 151° 30′ west and from latitude 62° 59′ to 64° 14′ north, although certain portions along the borders of the area so defined have not yet been mapped or are not included in the present report. (See fig. 6.) This portion of Mount McKinley National Park is now (1931) rapidly becoming accessible to visitors as the result of road construction and is approached at its eastern edge by way of the Alaska Railroad, built and operated by the Federal Government. The park here covers a complete section across the Alaska Range and offers a great variety of scenery, from the rugged, snow-capped mountains and glacier-filled valleys of the main divide to the open valleys and gentler slopes of the foothill ranges, with their great herds of mountain sheep and caribou. Constantly increasing numbers of visitors are each year coming to this northernmost of our national playgrounds, and it is believed that an understanding of the salient features of its geology will add to the appreciation and enjoyment of its remarkable scenery.

PREVIOUS SURVEYS

So far as is known, no white man had penetrated to this rather inaccessible portion of Alaska up to the end of the Russian occupa-

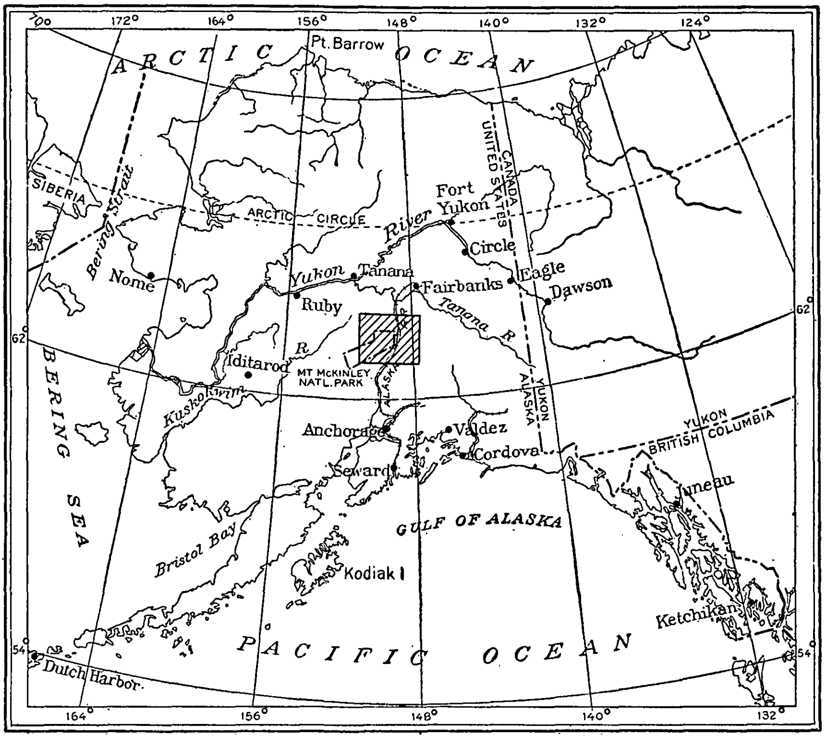

FIGURE 6.—Index map showing location of the eastern portion of Mount McKinley National Park

tion, in 1867, although Russian trading posts had been established on the lower Kuskokwim and Yukon Rivers and on Cook Inlet. These trading posts controlled the fur trade in the basins of the rivers that drain this part of the Alaska Range, and inasmuch as the interest of the traders was in the fur rather than in the exploration of this remote portion of the Russian Empire, no serious efforts were made by them to explore and map the headward portions of these great river basins.

Almost as great apathy prevailed for many years on the part of the United States Government, after the transfer of Alaska from

Russia. A few hardy pioneers, lured by the search for mineral wealth, came into the Territory from the east about 1872, and in 1878 two of them, Arthur Harper and A. Mayo, ascended the Tanana about to the present site of Fairbanks. In 1889 a number of white men made their way from the lower Tanana across to the Kuskokwim, probably by way of the Kantishna River and Lake Minchumina, not far to the northwest of the region here described, but all these earlier explorers of necessity followed those rivers on which they could navigate their small boats and shunned the rapid glacial streams that poured down from the rugged range to the south. They saw the snow-capped peaks of the Alaska Range in the distance, but there is no record that any of them actually set foot upon those mountains.

The first general realization that this great northern territory had possibilities of profit for the prospector and pioneer came with the discovery of rich placer gold diggings in the Canadian Klondike in 1897 and 1898 and with the historic stampede of gold seekers to the Yukon that followed. As a consequence of this awakened interest there arose a great demand for authentic information about Alaska, particularly with regard to routes by which the interior could be reached without crossing Canadian territory, as was necessary in following the route to the Klondike. In response to that demand several expeditions were sent out in 1898 by the United States Geological Survey and by the War Department, several of which carried explorations toward this region. Of the Geological Survey parties, G. H. Eldridge [1] and Robert Muldrow ascended the Susitna River by boat and crossed over to the headwaters of the Nenana River, just touching the region here considered along its southeast edge. In 1898 also Sergt. William Yanert, a member of an expedition sent out by the War Department in charge of Capt. E. F. Glenn, made a traverse up the Susitna River and into the upper basin of the Nenana River. That same year J. E. Spurr [2] and W. S. Post, of the Geological Survey, ascended the Skwentna River, portaged across to the Kuskokwim Basin, and descended that stream to its mouth. They thus explored a section directly across the Alaska Range, though well south of the Mount McKinley Park region. By these and other expeditions in 1898 and 1899 much knowledge was accumulated about the general geography of this part of Alaska, but the entire region here considered remained almost completely unexplored. The first accurate survey to be carried to it was made in 1902 by a Geological Survey party that included A. H. Brooks, D. L. Reaburn, and L. M. Prindle. This expedition left Cook Inlet in

[1] Eldridge, G. H., A reconnaissance in the Susitna Basin and adjacent territory, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 1–29, 1900.

[2] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Idem, pp. 31–264.

early spring with pack horses, ascended the Skwentna and Kichatna Rivers, discovered and crossed Rainy Pass, and thence followed the northwest flank of the Alaska Range to the Nenana River, down which they made their way to the Tanana River and thence to the Yukon. Throughout this journey through previously unexplored country topographic and geologic mapping was carried on continuously and a first knowledge was gained about the geography and geology of this great range. Beginning about 1903 and 1904 a large number of prospectors, attracted to the Tanana Valley by the discovery of rich placer deposits near Fairbanks, began to spread throughout the surrounding territory in the hope of discovering still other rich diggings. In 1905 promising ground was discovered in the Kantishna district independently by two separate parties, and, the news having reached Fairbanks, several thousand persons stampeded to this new camp. It soon became evident that paying ground was confined to a few creeks and that its extent was not large, so most of the stampeders left, but the gold mines of the Kantishna for many years served as the base of supplies for prospecting the country to the south and southeast until its geography became fairly well known to a number of these men. In 1906 L. M. Prindle made a hurried trip into the then newly discovered Kantishna placer district and published a brief description of its geology and placer deposits.[3] In 1910 topographic and geologic surveys were carried out by J. W. Bagley and S. R. Capps [4] along the north side of the Alaska Range between the Nenana and Delta Rivers, which border the area here discussed to the northeast, and in 1913 F. H. Moffit,[5] J. W. Bagley, and J. E. Pogue similarly surveyed an area on the south slope of the range and east of the Nenana River.

Between the years 1903 and 1913 a number of expeditions, organized to climb Mount McKinley, made more or less successful assaults on that mountain. Most of these have left records in book form,[6] but in many ways the most spectacular was that of Thomas Lloyd, William Taylor, Peter Anderson, and Charles McGonogill, Alaskan prospectors and miners, who with little preparation or financial backing set out to climb the mountain in February, 1910, and within a few weeks from the conception of their enterprise succeeded in planting a flag pole on the north peak of the mountain. Brief newspaper dispatches, largely discredited at the time, were the only

[3] Prindle, L. M., The Bonnifield and Kantishna regions: U. S. Geol. Survey Bull. 314, pp. 205–226, 1907.

[4] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, p. 64, 1912.

[5] Moffit, F. H., The Broad Pass region, Alaska: U. S. Geol. Survey Bull. 608, p. 80, 1915.

[6] Dunn, Robert, The shameless diary of an explorer, Outing Publishing Co., 1907. Cook, F. A., The top of the continent, Doubleday, Page & Co., 1908. Browne, Belmore, The conquest of Mount McKinley, G. P. Putnam's Sons, 1913. Stuck, Hudson, The ascent of Denali, Charles Scribner's Sons, 1914.

published record of their remarkable feat. None of these mountaineering expeditions attempted to carry out accurate surveys of the country they explored, although they did procure much valuable geographic information about the region. Construction work on the Alaska Railroad, built by the Federal Government from Seward to Fairbanks, was begun in 1915. Surveys carried out in connection with this and earlier railroad projects, both before and during construction, gave precise geographic information concerning a narrow strip along the line of the railroad but extended to no great distance on either side of the line.

In 1916 a geologic party in charge of S. R. Capps[7] and a topographic party in charge of C. E. Giffin left the Tanana River at the present site of Nenana and mapped the north flank of the range from the Nenana River westward to Muldrow Glacier and the outlying mountains of the Kantishna mining district. With construction work on the railroad in progress, prospecting was greatly stimulated at many localities throughout the Susitna Basin, and several of the more promising of these prospecting areas were visited by Capps in 1917, including that in the basin of the West Fork of the Chulitna River, and something was learned of its general geology.[8] Still further mapping was done in 1919 by Capps, T. P. Pendleton, and S. H. Cathcart, in the higher part of the range between the Nenana River and the East Fork of the Toklat River. The geologic results of that work were never published and are embodied in this report. Topographic mapping of an area on the south flank of the range from the basin of the West Fork of the Chulitna River eastward to the Nenana River was carried out in 1920 by J. R. Eakin. In 1925, during an expedition from the Nenana River westward into the Kuskokwim Basin, Capps[9] studied the geology of parts of the country between Toklat and the western edge of the area shown on the accompanying map. Also at various times during the last 10 years other members of the Geological Survey, including A. H. Brooks, P. S. Smith, and F. H. Moffit, have spent some time within this region. Stimulated by the growing public interest in the Mount McKinley National Park, there has grown up a considerable volume of printed material, both books and magazine articles, that treats of this region. These publications can not be listed here, but two that relate primarily to the region described in this report are one by the late Charles Sheldon,[10] who spent considerable time in this region before it was made

[7] Capps, S. R., The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 116, 1919.

[8] Capps, S. R., Mineral resources of the upper Chulitna region: U. S. Geol. Survey Bull. 692, pp. 207–232, 1919.

[9] Capps, S. R., The Toklat-Tonzona region: U. S. Geol. Survey Bull. 792, pp. 73–110, 1927.

[10] Sheldon, Charles, The wilderness of Denali, 412 pp., Charles Scribner's Sons, 1930.

a national park and who made a careful study of the distribution and habits of the wild animals, particularly in the basin of the Toklat River, and one by William N. Beach,[11] who describes with some detail and with excellent illustrations portions of the Mount McKinley Park region and its wild life.

PRESENT INVESTIGATIONS

As a topographic map of the region south of the Alaska Range extending from the basin of the West Fork of the Chulitna River eastward to the Nenana River was available and as that area adjoined an area north of the crest of the range the geology of which had been studied in 1919 but still remained unpublished, it was determined to continue the geologic mapping in the West Fork of the Chulitna-Bull River-Cantwell region, thus completing the reconnaissance study of a complete section across the Alaska Range and so outlining the major geologic features of that part of Mount McKinley Park most commonly visited by tourists. It was also considered important to revisit the mineralized area in the basin of the West Fork of the Chulitna River. Accordingly the writer was assigned to this task and arrived at Colorado station on the Alaska Railroad June 9, 1930, with two camp men, eight pack horses, and provisions for three months. G. W. Pearson served during the season as packer and Andrew Lelande as cook. To both these men the writer wishes to express his appreciation for faithful and efficient service. Field work was continued throughout the summer and ended at Cantwell September 11.

The geologic data presented in this report have been derived from the studies of a number of geologists through a period of 29 years. A. H. Brooks and L. M. Prindle in 1902, Prindle in 1906, F. H. Moffit in 1913 and 1930, and others have contributed. The writer himself has spent three full field seasons and parts of four other summers in this region. It is therefore impossible to credit accurately these workers with their individual contributions to the general result here given. Many preliminary conclusions have been discarded as fuller data became available. Furthermore, it should be remembered that all these studies were of reconnaissance nature only and that most of the expeditions into the region were made before the railroad was completed and while this region was difficult of access and without established trails, so that the working field season was consequently short. Many parts of the area shown on the accompanying map (pl. 4) have been studied hastily only in passing. Both from its geologic interest and from the fact that Mount McKinley Park is each year attracting an increasing number of visitors, the region deserves mapping on a larger scale and in much greater detail than has

[11] Beach, W. N., In the shadow of Mount McKinley, 289 pp., Derrydale Press, 1931.

so far been possible. There is no doubt that when this more detailed work is done some of the present conclusions concerning the geologic succession and structure will be modified and that many of the geologic units will be subdivided and their age more accurately determined. Nevertheless, it is believed that our present knowledge is sufficient to justify the issuance of this report, in the hope that it will give visitors to this extraordinarily attractive region a better conception of the natural processes that have resulted in the making of these mountains and the origin of the various rock formations that contribute to the scenic interest of the park. In the preparation of this report the writer has drawn freely from the published and unpublished conclusions of his fellow workers in the Alaskan branch of the Geological Survey, as well as from his own printed reports on this and adjoining areas, in order that information pertinent to this region, heretofore scattered in various reports, some of which are now out of print, should be assembled here in one place. The writer also wishes to acknowledge his indebtedness to J. B. Mertie, jr., who studied the thin sections of the rocks collected and who determined the types and the mineral associations of the igneous rocks.

GEOGRAPHY

DRAINAGE

General features.—As is to be expected of an area that embraces a section entirely across a great mountain range, the draining streams belong to two distinctive systems. All of the north slope of this part of the Alaska Range drains to the Tanana River, and so to the Yukon; the main tributaries that carry the mountain waters to the Tanana are the Kantishna, Teklanika, and Nenana Rivers. The south slope of the range here drains in part into the Chulitna River, a tributary of the Susitna, and in part into the Nenana River, whose curious course entirely across the range is described below. With a few minor exceptions, the smaller tributaries that drain this mountainous province head in glaciers, in the high mountains of the range, and so receive a large portion of their summer run-off from the melting ice. These glacial streams are all supplied with abundant rock detritus during the summer period of melting and are heavily charged with sand, gravel, and silt. The stream gradients are steepest near the valley heads, and there the streams are able to move coarse gravel and have built up extensive valley-floor deposits of gravel and sand over which they flow in many branching channels. These outwash gravel deposits are coarsest near the glaciers and become progressively finer downstream. As the gradient decreases downstream the coarser materials are dropped, and the stream loses its tendency to split up and flows as a single channel between banks of sand and silt.

Glacial streams are subject to rapid changes in volume, becoming swollen after warm, sunny days or after warm rains but decreasing in flow on cool, cloudy days. Near their heads there is also a conspicuous daily rise and fall, and the traveler soon learns that a stream which can be easily waded on foot in the early morning may become a roaring and entirely unfordable torrent in the late afternoon. In winter, when melting ceases, the glaciers become inactive, and the streams that drain them become low and run clear. Within the higher mountains, before the small streams have united in the main valleys, most of the glacial streams can be forded on foot at favorable places in ordinary stages of water. At greater distances from the crest of the range the smaller tributaries join into rivers that in many places are difficult or impossible to ford.

Chulitna Valley.—The Chulitna River, through a number of headward tributaries, receives the drainage from the south flank of the Alaska Range from Anderson Pass eastward for a distance of 27 miles. Within that distance there are two glaciers, in the two main westward tributary valleys, which are each 7 miles or more long, and which together have an area of at least 24 square miles, and there are also more than a score of smaller glaciers each of which contributes its quota of water during the summer season of glacial activity. The West Fork of the Chulitna River itself, from the glaciers in which it heads to a point a few miles below the mouth of the Bull River, flows over broad gravel bars. In places there are a large number of channels, and there the stream can be forded on horseback, or even on foot at all times except in periods of exceptionally high water. Nevertheless this stream discharges a large volume of water, is swift, and where confined into one or two channels is unfordable during the height of the melting season. The Bull River, the largest tributary of the West Fork of the Chulitna River, likewise flows over broad gravel flats in its upper basin. About 10 miles above its mouth, however, it enters a rock canyon, has few gravel bars, and is at most times and most places too deep and swift to be safely fordable on foot.

Nenana Valley.—East of the Bull River Valley the south slope of the range in this region drains to the Nenana River. That peculiar stream, after gathering the drainage from what would normally be the Pacific slope of the range for a distance from east to west of over 60 miles, leaves the broad, open valleys near Broad Pass and turns abruptly northward to flow through a relatively narrow, steep-walled gorge entirely across the Alaska Range to join the Tanana River. As shown in the section of this report that treats of the effects of glaciation, this diversion of waters from the Pacific to the Bering Sea drainage was brought about by the filling of the Susitna Basin by glacial ice during Pleistocene time. In the area here considered the principal tributaries of the Nenana are the Cantwell and Jack Rivers, Windy and Riley Creeks, and Yanert Fork. The Cantwell River and Windy Creek receive the waters from the closely spaced streams draining the crest of the range between the basin of the Bull River and the Nenana Valley. From the east the main head of the Nenana River and Yanert Fork drain from large glaciers in the vicinity of Mount Hayes, flow westward parallel to the trend of the range, and then enter the gorge northward through the range to the great Tanana lowland. Above the junction of the Jack and Nenana Rivers both those streams can be forded by horses in ordinary stages of water, as can Yanert Fork above its mouth, if the best fords available are chosen. Below the mouth of Yanert Fork the Nenana River is almost nowhere fordable during the summer months.

Teklanika Valley.—The Teklanika River and its tributaries the Savage and Sanctuary Rivers drain a considerable area in the northeast corner of Mount McKinley National Park. The Savage River does not head against the crest of the range but through a number of moderate-sized creeks receives the drainage water from an area along the lower flank of the range. Its basin contains no glaciers, and the fluctuations of the river are therefore controlled by other factors than those which dominate in the glacial rivers of the region. Both the Sanctuary and Teklanika Rivers head in the rugged mountains at the crest of the range, are fed by numerous small glaciers, have extensive flood-plain deposits of outwash gravel, and vary in volume of flow according to the rapidity of melting in the snow and ice fields. North of the park boundary these three streams join and empty into the Tanana River some miles below the town of Nenana.

Kantishna Valley.—All of the north slope of the Alaska Range from the basin of the Teklanika River westward to a point near the southwest border of the park, a distance of 80 miles, drains into the Kantishna River and thence to the Tanana. In the region here under consideration the Toklat River, a large eastern tributary of the Kantishna, and its branches the East Fork of the Toklat River and Stony Creek all head in the high mountains, flow northward, and join in the lowland to reach the Kantishna 52 miles above its mouth. The main Toklat and the East Fork both drain from the summit of the range, are fed by numerous glaciers, and in summer are heavily charged with débris and flow with swift current over extensive gravel bars. The Sushana River heads on the outer flank of the range and is normally a clear stream. Stony Creek has one headward tributary that drains from the high peaks of the Alaska Range and is moderately turbid from glacial waters, but most of its drainage comes from the ice-free outer hills of the range and from the Kantishna Hills to the west and is clear. All these streams, where crossed by the route of the road from McKinley Park station to Muldrow Glacier, are normally of only moderate depth, though swift, and can be forded on foot. During occasional periods of high water, however, any of them may be dangerous or impossible to ford.

West of the Toklat Basin the streams of this region flow to the McKinley Fork of the Kantishna River, or to the Bearpaw River, a Kantishna tributary that carries only clear water and drains the west face of the Kantishna Hills. The McKinley Fork has its source in Muldrow Glacier, the largest glacier on the north slope of the Alaska Range. Muldrow Glacier is 40 miles long, has an area of more than 75 square miles, and is formed by several vigorous ice streams that pour off the northern flank of Mount McKinley and the high peaks east of it. The vigorous glacial stream that drains this glacier and forms the head of the McKinley Fork is fordable on foot in summer only in that portion of its broad gravel flat, for some miles below the ice edge, where the stream branches into a multitude of small channels.

None of the streams in this region are navigable even for small boats, and almost all are characterized by swift current, turbid water, and bouldery beds.

RELIEF

In general topographic setting the region here considered is a cross section, 60 to 70 miles long, of the great mountain arc of the Alaska Range. That range extends through central Alaska, roughly paralleling the Pacific coast line, from the vicinity of Iliamna Lake and lower Cook Inlet in a north-northeast direction for nearly 300 miles and then gradually curves to northeast, east, and southeast to the international boundary, a total distance of 650 miles of unbroken mountain chain. Within that distance the width from flank to flank ranges from 35 to 70 miles. The mountains rise from lowland or piedmont areas 2,000 to 3,000 feet above sea level, and the summit peaks reach altitudes of 6,000 to 7,000 feet in the lower portions of the range. The higher peaks attain altitudes of 11,000 to 13,000 feet at a number of places, and the range culminates at the crest of the great arc, just west of the region here treated, in the companion peaks Mount Foraker, 17,000 feet high, and Mount McKinley, towering 20,300 feet, the loftiest peak on the continent. Within the area shown on the accompanying map there are peaks just south of Muldrow Glacier that are over 11,500 feet high. Around the borders of West Fork Glacier there are several peaks 8,000 feet in altitude, and farther east many summit peaks reach 7,000 feet, but few reach 8,000 feet. In this part of the range glaciers form on mountains 7,000 feet or more in height, and in general the size of the glaciers increases with the height of the mountains, though certain other factors, such as the direction of exposure of the mountains to the sun and the area of the catchment basins above the permanent snow line are also factors in determining the size of the glaciers. The largest glaciers in this part of Alaska rise upon the flanks of Mount McKinley and of the neighboring high peaks in this part of the range. Muldrow Glacier, the largest inland-facing ice stream of the range, projects its lower end into the southwest corner of the region here described.

Near the eastern portion of Mount McKinley National Park the Alaska Range is sharply limited, on its southeast border, by the depression through which the Chulitna, Cantwell, and Jack Rivers flow. This depression is continuous to the south with the Susitna lowland and to the east through the valleys of the upper Nenana and Susitna Rivers with the great Copper River Basin. There are still many unsolved problems concerning the history of these lowlands, but a study of the topographic map indicates the obvious relation between them, and it is apparent that the headwaters of the Nenana River once flowed through the low divide eastward into the Jack River Valley, and thence southward through the Chulitna Valley to the Susitna, and the river that followed that course quite likely drained a large area in what is now the Copper River Basin. The present canyon of the Nenana River across the Alaska Range is no doubt the result of a glacial diversion.

On its inland slope the boundaries of the Alaska Range in this sector are less sharply defined, for on its flank there are two or more minor parallel ridges of mountains separated from one another by broad depressions, and these foothill ranges abut, at their west end, against a large compact group of mountains known as the Kantishna Hills. The foothill ridges and the Kantishna Hills are all mountain masses of considerable height and area and are hills only by comparison with the lofty summits of the main Alaska Range. To the west and north these outlying ridges give way to the great lowland that extends from the upper Tanana River westward to the Kantishna Basin and thence southwestward into the basin of the Kuskokwim River and that separates the Alaska Range from the various upland masses of interior Alaska. The Tanana and Kantishna lowlands lie to the north and west of the area here under discussion, but portions of the basins that separate the foothill ranges from the main range and from one another are shown on the accompanying map (pl. 4) along the park automobile road between McKinley Park station and the Teklanika River and along the northern edge of the park between the Savage River and Stony Fork.

CLIMATE

The section across the Alaska Range here under consideration has a considerable variety in climate, as has long been recognized by those living in the region. Within this area accurate weather records have been kept only at McKinley Park station, and the climate there may be considered fairly representative of the high mountain belt. The weather in the high mountain is, however, quite different both from that of the Chulitna-Nenana lowlands, to the south, and from that of the foothill belt and the Tanana lowland, to the north. Records taken at Talkeetna, in the Susitna Basin, about 80 miles south of Broad Pass, and at Nenana, in the Tanana Valley, 60 miles north of McKinley Park station, the nearest points at which records have been kept, show a striking change in both temperature and precipitation from the Susitna Basin, on the Pacific slope, across the range to the interior basins of Alaska. The following table gives the available weather records for McKinley Park, Nenana, and Talkeetna. Talkeetna has the highest monthly mean, daily mean maximum, and daily mean minimum temperature, as well as much the highest precipitation and snowfall. The McKinley Park temperature is intermediate between that of Talkeetna and Nenana, though it more closely resembles that of Nenana. Its annual precipitation is only slightly more than that of Nenana, though less than half that of Talkeetna. In summary it may be stated that the Susitna Basin and the south slope of the Alaska Range have more cloudy days, much more rain and snow, and a milder temperature than the north slope of the range, and that the foothills and lowlands on the north slope have clearer weather, wider extremes of temperature, and a rainfall that classes that part of the region as semiarid.

Temperature (° F.) and precipitation (inches) at McKinley Park station, Nenana, and Talkeetna, Alaska

Station [a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Monthly mean temperature													
McKinley Park (6)	1.6	6.4	13.6	24.0	42.1	54.3	56.1	53.9	43.1	28.9	15.6	0.7	28.4
Nenana (8)	−5.9	3.0	8.2	27.6	50.0	57.6	61.5	58.0	44.6	26.7	3.4	−7.9	27.2
Talkeetna (11)	8.4	16.7	21.6	32.9	45.5	54.6	58.1	55.2	39.9	34.7	20.6	9.7	33.2
Daily mean maximum temperature													
McKinley Park (5–6)	11.0	16.9	23.9	35.5	53.3	64.2	68.1	65.6	51.1	38.1	24.0	9.5	38.4
Nenana (5)	−2.0	12.6	21.0	39.3	55.7	68.0	72.3	68.0	54.8	32.5	9.3	2.2	36.1
Talkeetna (8)	19.6	26.8	35.0	44.7	59.9	69.8	70.3	67.5	57.2	44.5	30.1	18.7	45.3
Daily mean minimum temperature													
McKinley Park (5–6)	−7.8	4.1	3.5	14.3	30.8	40.4	44.3	42.1	33.6	19.7	6.6	−6.3	18.8
Nenana (5)	−23.5	−6.6	−2.3	14.3	34.6	46.6	51.1	46.6	35.0	18.3	−6.0	−15.7	16.0
Talkeetna (8)	−0.8	3.6	10.8	20.5	31.6	40.9	45.4	44.0	35.0	26.7	12.3	.2	22.5

[a] Figures in parentheses indicate the number of years' record.

Temperature (° F.) and precipitation (inches) at McKinley Park station, Nenana, and Talkeetna, Alaska—Continued

Highest temperature of record

Station [a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
McKinley Park (6)	47	48	51	57	68	89	85	83	70	69	56	47	89
Nenana (6)	32	46	52	58	75	84	94	84	76	61	41	39	94
Talkeetna (11)	45	48	55	60	79	88	90	88	71	68	52	41	90
Lowest temperature of record													
McKinley Park (6)	−52	−47	−28	−33	4	25	31	28	2	−15	−34	−54	−54
Nenana (6–7)	−63	−51	−50	−26	18	35	37	30	15	−17	−49	−56	−63
Talkeetna (11)	−48	−33	−24	−23	20	27	31	27	20	−8	−30	−41	−48
Monthly and annual normal precipitation													
McKinley Park (6)	.50	.57	.59	.93	1.31	2.31	2.25	1.83	1.80	.92	.45	.63	14.09
Nenana (8)	.38	.51	1.04	.36	.66	1.50	2.63	1.98	1.58	.80	.26	.30	12.00
Talkeetna (11)	1.68	2.18	1.85	.91	.95	1.63	3.84	4.50	4.80	4.00	1.54	1.81	29.69
Monthly and annual snowfall													
McKinley Park (4–6)	11.3	9.1	7.5	1.9	Tr.	0	0	0	2.3	6.5	7.6	9.2	55.4
Nenana (8)	5.9	5.3	9.6	3.4	1.2	0	0	Tr.	.3	7.7	4.5	4.0	41.9
Talkeetna (6–8)	22.9	23.2	28.4	13.4	.5	0	0	0	2.6	10.3	15.8	24.6	141.7

[a] Figures in parentheses indicate the number of years' record.

VEGETATION

Even the lowest portions of the area shown on the accompanying map (fig. 7) lie near timber line, and trees occur only along the valleys of the main streams. On the north slope of the Alaska Range few valleys contain trees at altitudes of over 3,000 feet, and many areas of much lower altitude are unforested. The lower slopes of the valley walls of the Nenana River contain scattered trees throughout this area, but the automobile road and trail from McKinley Park station to Muldrow Glacier crosses the northward-draining valleys at or near timber line, and few trees are found between it and the crest of the range. Figure 2 shows the areas in which trees occur. In the valley heads willows of sufficient size for use in camping can generally be found some distance above the last trees, but the upper 10 miles or so of most valleys is devoid even of brush.

The commonest variety of tree is spruce, but cottonwood grows on stream bars and benches in favorable places. Cottonwood is able to grow at somewhat higher altitudes than the spruce and in many valleys extends somewhat farther upstream than the spruce, but at the higher altitudes the trees are small and crooked. In most places the spruce trees also are small, those reaching a diameter of 18 inches to 2 feet being exceptional. Little clear lumber can be obtained from them, and they are valuable only for local uses. There is no merchantable timber in this region. South of the axis of the range the upper limit to which trees grow is about 2,700 feet, and there, too, are many areas, both in the mountain valleys and in the broader Chulitna-Cantwell lowland, in which trees are absent. The camper in any of the high valleys of the region must either carry

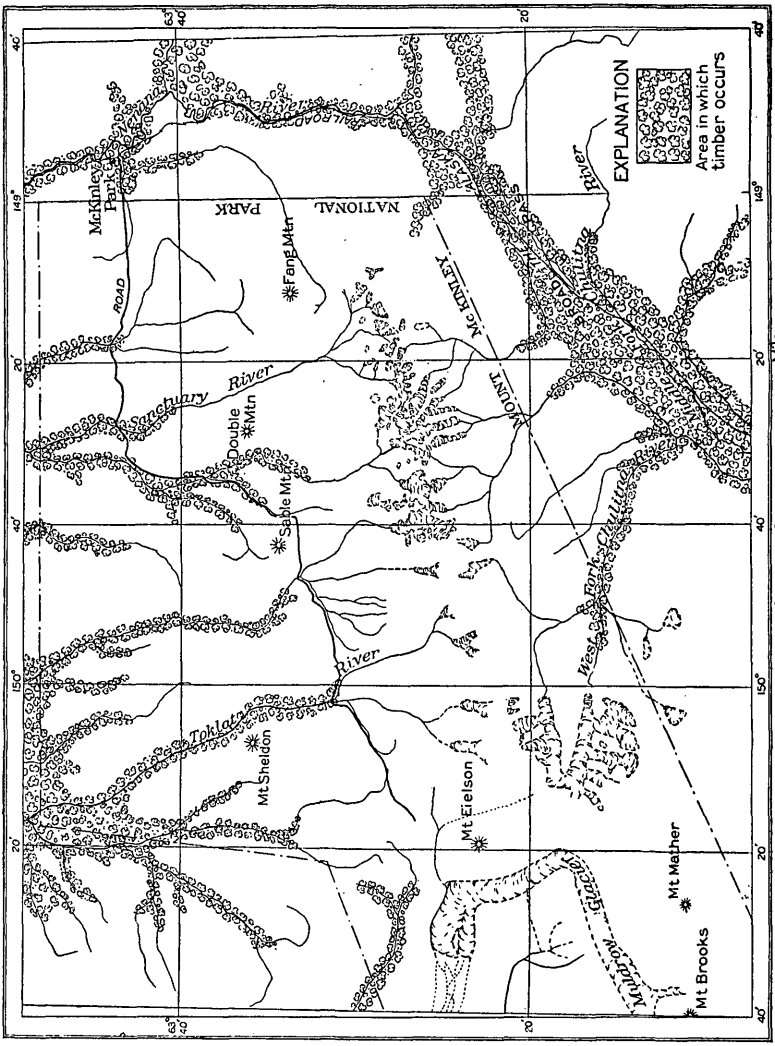

FIGURE 7.—Distribution of timber in eastern portion of Mount McKinley National Park

both tent poles and fuel along or must rely on green willows, which can be burned in a stove but which are in many places much too small and crooked to serve as tent poles, and the supply of even these is at many places inadequate for more than a short stay.

Grass for forage for horses is generally abundant on the north side of the range except in the upper valley heads, and pack horses will keep in good condition during the summer if allowed sufficient opportunity to graze. In addition to bunch grass and red top, the commoner grasses, a nutritious vetch in places grows on the gravel bars, and horses also eat the leaves and tender shoots of certain species of willows. On the south slope of the range forage for stock is even more abundant and more generally distributed than on the north slope. The growing season, however, in this high country is short. The earliest appearance of green grass may be as late as the middle of June, and killing frosts usually occur by the middle of September, but lighter frosts may be expected in the higher valleys during every month of the summer. Bunch grass and the so-called "pea vine" retain some nutritive value after they have been killed by frost, but red top and other forage plants are worthless, and horses must be fed hay and grain if they are expected to do heavy work except during the period from June 1 to October 1.

In addition to the trees there are numerous brushy plants, notably alders and several varieties of willows. Smaller shrubs include high-bush cranberry and mountain ash. Blueberries grow in profusion on many slopes, especially near or above timber line, and low-bush cranberries and currants are found locally.

Little attempt has been made at agriculture in this region. Small gardens have been planted at Colorado, Cantwell, and McKinley Park, and the hardier varieties of vegetables have been raised. Some hay and oats have been planted at Cantwell but with only moderate success. In most of the Susitna Basin hay crops and wild hay grow well, but the uncertain weather during the summer makes it difficult to cure hay properly. In view of the high altitude of this region and the likelihood of frost during any month in the growing season, the agricultural possibilities of this part of Alaska do not seem favorable, though good grazing for stock is available for three or four months each year.

WILD ANIMALS

The region that includes Mount McKinley National Park is remarkable for the abundance of big game animals, particularly the part that lies on the north slope of the Alaska Range. In their natural state, before restrictions were placed on hunting, the mountains of the Sanctuary, Teklanika, Toklat, and McKinley Fork Basins were the home of thousands of the white mountain sheep, and great herds of caribou ranged in both the higher mountains and the foothill ridges. Since the prohibition of hunting within the park boundaries these herds have increased in number, and the animals have grown tamer, so that they now offer one of the great attractions to visitors to the park. For some reason the south flank of the range is less attractive to these animals, and there are few sheep in the basins of the West Fork of the Chulitna River and the Bull River, though there are numbers of them in the Cantwell and Windy Creek Basins. Caribou, too, though present in scattered bands in the valleys of the south slope, are much fewer there than on the interior side of the range. In this part of the park there are a few moose, whose range is restricted to the timbered and brushy valleys. Both black and grizzly bears are present, and the smaller animals include lynx, fox, wolverine, beaver, mink, ermine, marten, marmot, ground squirrels, rabbits, and mice. Rabbits and ptarmigan form the main food supply of all the carnivorous fur-bearing animals and the birds of prey, and as both rabbits and ptarmigan vary greatly in abundance from year to year, so also do the animals and birds that prey on them. In 1929 and 1930 the rabbits had almost entirely disappeared, and the ptarmigan were scarce, and this scarcity resulted in a great diminution in the number of fur-bearing animals and of hawks and owls.

POPULATION

Aside from the park officials and rangers and the agents and section men employed on the Alaska Railroad, there are probably no more than a dozen permanent white residents in the region here under discussion. Small fur farms have been established at Colorado and at McKinley Park station, and a few trappers and others have cabins at the railroad at which they spend part of their time. Cantwell, the point of departure from the railroad for the placer mines of the Valdez Creek district, has a road house and store at which staple supplies can be had. McKinley Park station is the point of entrance for the exploited portion of the park, and its population varies with the season. In winter it has only a few residents. The park headquarters are just within the eastern border of the park, some 2 miles from the railroad. The automobile road now under construction from the railroad to the lower end of Muldrow Glacier gives employment to a varying number of men, depending on the season. This road and its extension by trail to the westward form the most used summer route to the Kantishna mining district.

About 15 years ago vigorous prospecting of gold, copper, and antimony lodes was in progress in the basin of the West Fork of the Chulitna River, and 30 or 40 men were engaged there. All but one or two of these men have abandoned their claims and left.

A few natives from the upper Susitna Basin come to Cantwell to trade, but there are no permanent native settlements in this area.

Although prospecting is authorized by law within the boundaries of Mount McKinley National Park, and title to mining property can be obtained, so far no mining claims have gone to patent, and no productive mining is now in progress within the park.

ROUTES OF TRAVEL

Before the construction of the Government built and operated Alaska Railroad, which was begun in 1915 and completed in 1924, this region was difficultly accessible and was visited by few persons. Now and then a traveler journeyed by dog sled in winter from the terminus of the old Alaska Northern Railroad, on Cook Inlet, along the general route now followed by the Alaska Railroad to the Tanana Basin, but that travel was over the frozen streams, and no land trail had been established. Most winter travelers to interior points then used the Richardson Highway from Valdez, and later from Chitina, on the Copper River Railroad, to Fairbanks. At that time there were no inhabitants in what is now Mount McKinley Park, and the only visitors were a few prospectors, hunters, or trappers. The only near-by settlements were in the Kantishna mining district, and travelers to the diggings there went either by dog sled, in winter, along a route from the Nenana River north of the foothills, and outside of this region, or by boat, in summer, following the Tanana and Kantishna Rivers.

The completion of the Alaska Railroad entirely changed the whole aspect of travel and freight transportation to this region. Regular passenger and freight train schedules were established along the eastern edge of the park, and comfortable trains deliver passengers at the various railway stations in a little more than a day from Seward. The chief interest in this region now centers about the wonderful mountain scenery and abundant wild life of Mount McKinley Park, and a constantly increasing number of visitors is attracted to the park each summer. No trails have been established and no accommodations for visitors have been provided in that part of the park that lies south of the crest of the range, attention to the development of the park having been confined to the north slope. McKinley Park station is the official entrance to the park. A well-organized company meets all trains with automobile stages during the tourist season and transports visitors to comfortable camps some distance into the park. Construction of a good automobile road westward from McKinley Park station was commenced several years ago, and this work has progressed each year. In 1930 the road was open to the East Fork of the Toklat River, and trucks had been taken over unfinished road as far westward as Stony Creek. By the fall of 1931 the road was completed almost to Thorofare Pass, and it was proposed to extend it still farther westward to a site where a hotel was projected, within view of Mount McKinley. From Thorofare Pass a horse trail follows down the McKinley Fork past Wonder Lake and to the placer and lode mines and prospects of the Kantishna mining district. This wagon road and the trail above mentioned constitute the only established trails in the region, yet the open valleys, broad gravel flood plains, and many low passes from one valley to the next make travel throughout the region easy, either by dog sled in winter or by horses in summer. On several occasions horses have been taken from the lower end of Muldrow Glacier up its east side to Anderson Pass and thence down the West Fork Glacier to the head of the West Fork of the Chulitna River, but this pass should be attempted with horses only during the late summer, when the snow has largely melted off the surface of the glaciers. This same route has been traveled many times by dog sled in winter. The only other feasible pass across the range in this area, in addition to the route followed by the railroad, is that by way of Windy Creek across the divide into the head of Riley Creek. One mountaineering expedition did succeed in taking horses across the range over the glacier at the head of the Teklanika River and down into the head of the Bull River, but this route was attempted only as a desperate emergency and is both difficult and dangerous. Already the demands of summer visitors have stimulated the development of trails along the main stream valleys, and no doubt within a short time the park will be crisscrossed by a network of foot and horse trails that will make all parts of it easily accessible.

Cantwell station, at the junction of Cantwell Creek and Jack River, is at the west end of a horse trail that leads to the placer diggings of Valdez Creek and of a winter sled route to that camp. Formerly Valdez Creek was generally approached from the Richardson Highway in the Copper River Valley, but since the establishment of service on the Alaska Railroad that route has been little used.

GEOLOGY

PRINCIPAL FEATURES

The areas of outcrop of the rock formations that have been differentiated in this region are shown on Plate 4. The field work on which this map is based has been done through a period of 28 years by different geologists and has all been either of exploratory or reconnaissance character. The object in view during this work has been the procuring of general information concerning the broader facts of structure and of rock distribution, rather than the detailed study of smaller areas, the finer discrimination between rock types, and the final subdivision of rock groups into closely correlated lithologic units. The general studies so far made have been a necessary preliminary to the more detailed studies that will be made later, as time and funds permit. In the early days of exploratory mapping in this region many of the outstanding features of its geology were recognized and correctly interpreted. Others of the earlier views have been modified, as further field observations accumulated. No doubt later detailed work will further modify present conclusions as to the areal distribution of the rocks and will result in some changes in the age determinations of the rock units here differentiated and in the subdivision of those larger units into smaller ones. One of the great difficulties encountered by geologists in this region is the general scarcity of fossils. Less than half a dozen of the rock groups have yielded determinable fossils at all, and these at very few localities. Furthermore, all the rock groups, from pre-Paleozoic to Tertiary, have been regionally and locally metamorphosed, so that at some localities Tertiary sediments are completely schistose. As a result, degree of metamorphism alone is an unreliable criterion upon which to make correlations. Although the present writer has made full use of the work of others in this field, notably A. H. Brooks and L. M. Prindle, and here acknowledge his indebtedness to them, nevertheless he himself has studied most of this region in more detail than was possible for them, and he has therefore somewhat altered their mapping and their correlations, and for this he alone takes the responsibility.

As shown on the accompanying geologic map, there are two rock groups that are believed to be definitely of pre-Devonian age. One of these is considered to be pre-Cambrian, and the other pre-Devonian Paleozoic. A group of rocks lying near the center of the range contains limestone of Middle Devonian age, and also a great thickness of sediments both above and below the horizon at which the Middle Devonian fossils have been found. These associated rocks have so far failed to yield fossils. They are believed to be in part pre-Devonian and in part later than Middle Devonian, but all are definitely younger than the pre-Cambrian schist and also younger than the group of schist, limestone, slate, and serpentine of pre-Devonian Paleozoic age. Furthermore, they are definitely pre-Triassic. Along the north flank of the range there is another group of metamorphic sediments whose age is not yet accurately known. They are here grouped as undifferentiated Paleozoic rock. To the south, in the Thorofare Pass-Divide Mountain region, is another group of Paleozoic rocks, of undetermined age, which may be equivalent to or younger or older than the undifferentiated Paleozoic rocks on the north flank of the range. Their relations to the rocks of Middle Devonian age have not been determined.

The rocks of the region that are here referred to the Mesozoic include greenstone flows and tuffs that underlie a series of Triassic rocks and may possibly be in part of late Paleozoic (Permian) age;

a Triassic group that includes slate, argillite, graywacke, tuff, and some limestone; and a thick group composed mainly of black shale but containing also graywacke beds and a little limy shale that is, in part at least, of Upper Jurassic or Cretaceous age. All these sediments are cut by dikes, sills, and stocks of intrusive rocks, including coarse-grained granitic materials.

The Tertiary deposits of the region include a thick series of shale, conglomerate, and sandstone—the Cantwell formation—that has yielded fossils identified as of Eocene age. It is succeeded unconformably by a series of softer shale, sandstone, and conglomerate that also contains lignitic coal. This coal formation is in turn overlain unconformably by a heavy deposit of Tertiary gravel—the Nenana gravel. The Cantwell formation and the coal-bearing series are cut by dikes and sills of various sorts of granular intrusive rocks and are interbedded with lava flows.

Quaternary deposits include glacial morainal material of at least two stages of Pleistocene glaciation, present glacier deposits, outwash gravel, terrace deposits, and the deposits of present streams, as well as accumulations of talus, products of rock disintegration and decomposition in place, soils, and peat.

All these materials except those of Pleistocene and Recent age have suffered varying degrees of metamorphism. The main structural features of the Alaska Range lie parallel to the axis of the range, and the region has been the scene of repeated mountain-building processes that have recurred at intervals from pre-Cambrian time to the middle of Tertiary time. There was probably intense pre-Cambrian deformation and metamorphism of the preexisting rocks, perhaps at many times, and the structure of the pre-Cambrian schists is parallel to the more recent folding and faulting. The pre-Devonian Paleozoic schists, slates, and serpentines on the south flank of the range indicate another period of deformation. The group of Devonian and associated rocks is recrystallized, folded, and crumpled, in lesser degree than the pre-Devonian Paleozoic schists and slates, but more than the Triassic beds. The Triassic rocks are somewhat more metamorphosed than the overlying Mesozoic shale series. Possibly some folding occurred between the deposition of the late Mesozoic and the earliest Tertiary rocks here represented, but this has not been definitely established. Close folding, crumpling, and faulting occurred after the deposition of the Cantwell, but before the coal-bearing formation was laid down, and intense metamorphism took place along the zone of the great fault that accompanied this period of mountain building, so that Tertiary conglomerates were stretched and sheared and became schistose. The final upthrust of this region occurred after the coal-bearing formation was laid down and involved also at least a part of the overlying gravel. Since this period of Tertiary deformation the region has remained relatively stable.

The geologic history of this part of Alaska is highly complex, and as yet only some of the major events can be outlined. Fossils, upon which the geologist must depend to determine the age of the different formations, are extremely scarce or lacking throughout this region, and not more than a dozen collections in all have been made upon which to determine the stratigraphic succession of formations which range in age from pre-Cambrian to Recent and which cover an area of more than 2,300 square miles. The intense regional metamorphism and complex structure of the older rocks add to the difficulty of determining the stratigraphic relations of their various units, and the local metamorphism to schists of sediments as young as the Tertiary makes correlation of formations on the basis of degree of metamorphism alone uncertain. Furthermore, there are many apparent breaks in the stratigraphic record, representing long periods during which parts of this area were land and no sediments were deposited, or such sediments as once were present have been removed by erosion or covered from view by younger overlying materials. Some of these breaks are doubtless real. Other apparent breaks may be represented by sediments that have yielded no fossils and that are therefore here erroneously grouped with other rocks of known age.

In addition to the periods of folding and metamorphism mentioned above there may have been many other periods of widespread uplift, without folding and crumpling, the record of which is difficult to obtain.

The following table gives the stratigraphic sequence for this region, in so far as it is now known:

Quaternary:

- Gravel, sand, and silt of the present streams; peat and impure organic deposits or muck; talus accumulations; soils and products of rock disintegration in place; deposits of existing glaciers.
- Terrace and bench gravels, some of glaciofluvial origin.
- Glacial deposits of at least two stages of Pleistocene glaciation.

Tertiary:

- Nenana gravel (loosely consolidated elevated gravel and sand of yellow or buff color, locally tilted). Eocene or later.
- Coal-bearing formation (generally light-colored soft sandstone, clay, and gravel, little indurated, locally containing lignite). Probably Eocene. Associated with these sediments are minor amounts of lava flows and tuffs.
- Cantwell formation (generally dark indurated shale, conglomerate, grit, and sandstone, with some carbonaceous material, locally sheared to stretched conglomerate and schist). Of Eocene age. Associated with these sediments are granitic intrusive stocks and dikes, sills, lavas, and tuffs that in places predominate over the sedimentary rocks.

Mesozoic:
- Upper Jurassic or Cretaceous. Mainly black shale, with minor amounts of thin-bedded graywacke, conglomerate, and shaly limestone. Generally tilted and locally folded, crumpled, and faulted.
- Triassic. Alternating shale and graywacke beds but containing also conglomerate, tuff, and limestone.
- Greenstone flows and tuffs in part of Triassic age.

Paleozoic:
- Greenstone flows and tuffs, probably in part of Permian age.
- A considerable thickness of shale, slate, graywacke, and thin-bedded limestone lying above a massive crystalline limestone containing fossils of Middle Devonian age, and a great thickness of shale, thin-bedded limestone, and conglomerate lying below the Middle Devonian limestone. Possibly includes beds both younger and older than Devonian.
- Undifferentiated Paleozoic rocks, including argillite, slate, graywacke, chert, thin-bedded limestone, and some phyllite and schist, the age of which is not known.
- Pre-Devonian rocks, including slate, schist, serpentine, and limestone.

Pre-Cambrian:
- Birch Creek schist (micaceous and quartzitic schist and phyllite) and associated metamorphosed intrusive igneous material.

Intrusive rocks:
- All the sedimentary rocks from pre-Cambrian to the Tertiary coal measures are cut by dikes, sills, and stocks of a great variety of intrusive rocks.
- Granitic intrusive rocks cut all the sediments up to and including the Cantwell.

In pre-Cambrian time a great thickness of sediments, including shale, sandstone, and a little limestone, was deposited, later cut by both basic and acidic intrusive rocks, and then severely metamorphosed through folding and recrystallization into the present Birch Creek schist, which now includes micaceous and quartzitic schists and phyllites. The high degree of metamorphism that these rocks have undergone was probably not accomplished during any single period of deformation but more likely represents the results of repeated periods of mountain building, perhaps through a long time range. The structural features within these schists, however, show a pronounced tendency to lie parallel with the axis of the present Alaska Range, and this indicates that throughout much of the known geologic history of this part of Alaska the forces that brought about rock deformation and mountain building have been applied in the same general direction, resulting in folding in a direction nearly east and west. All the later folds have this same general trend.

After the deposition and metamorphism of the Birch Creek schist there was a long interval that is unrepresented by any deposits so far recognized in this district. This gap does not necessarily mean that no rocks were laid down during this interval, but only that if such rocks were deposited they were later removed by erosion, or that if present they have not yet been identified. The Birch Creek schist is overlain by a group of altered rocks—slate schist, slate, limestone, and serpentine—which are exposed only as a narrow band immediately north of the great eastward-trending fault that lies just south of the mountain crest. The age of this group of rocks is not known, but it is believed to be younger than the Birch Creek and older than the Devonian succession. It is less metamorphosed than the Birch Creek and more altered than the overlying Devonian rocks, thus indicating another period of metamorphism after the Birch Creek and before the middle Paleozoic.

Next younger than the pre-Devonian slate, schist, limestone, and serpentine group is a great series, many thousand feet thick, of conglomerate, shale, thin-bedded limestone and shale, quartzite, graywacke, and a massive limestone that contains some fossils of Middle Devonian age. Most of these sediments are folded, recrystallized, or otherwise metamorphosed, so that fossils are extremely rare. There are several thousand feet of conglomerate, shale, and thin-bedded limestone and shale below the horizon at which Middle Devonian fossils were found, and a similarly great thickness of beds above that horizon. Quite likely rocks laid down both before and after Middle Devonian time are included in this group. At any rate, these rocks tell the story of a long period in the midst of Paleozoic time during which this region was beneath the sea and receiving heavy deposits of shallow-water sediments. Later these same beds were uplifted, folded, and in part recrystallized.

This thick series of Paleozoic sediments is followed by another long gap in the geologic record, which represents a time when this area was continually a land mass, and so subject to erosion, or, if the area was ever submerged, the rocks laid down during that submergence were later stripped away and removed during a period of emergence. This time gap extends nearly to the end of the Paleozoic or possibly to the beginning of Mesozoic time. The next younger rocks represent the outpouring of basic lavas and the accumulation of basic volcanic tuffs, part of which were laid down under water and are now pillow lavas. These rocks bear no fossils but probably correspond in age to other basic lavas elsewhere in Alaska that were poured out from Permian possibly into Triassic time.

Triassic time witnessed the deposition of several thousand feet of shale, conglomerate, tuff, graywacke, and some limestone. These beds were probably somewhat folded during late Triassic or early Jurassic time. They were succeeded by a series several thousand feet thick, consisting mainly of black shale, but containing also some interbedded graywacke, conglomerate, and shaly limestone, which was deposited in late Jurassic or Cretaceous time. The upper and lower age limits of this series of sediments are not accurately known. If any mountain building took place after this series was laid down and before the beginning of Tertiary time it was accomplished more by regional uplift than by local deformation.

The earliest Tertiary sedimentation in this region is represented by the Cantwell formation, which comprises several thousand feet of black shale, conglomerate, graywacke, and sandstone. These beds were laid down in fresh water and carry plant remains but no shells. They have been determined, from their plants, to be of Eocene age, but they were certainly indurated, uplifted, folded, and eroded before the coal-bearing formation, also probably Eocene, was laid down. The coal-bearing formation, which in places reaches a thickness of nearly 2,000 feet, also consists of fresh-water beds, including sand, gravel, and shale, with many coal beds. The clastic sediments are only moderately indurated, and their physical appearance indicates that they are considerably younger than the Cantwell. An uplift along the axis of the present Alaska Range locally tilted and folded the coal-bearing formation and caused the deposition along the flanks of the uplifted area of an extensive sheet of gravel, the Nenana gravel. With the further growth of the range a part of this gravel was also tilted and uplifted. Since that uplift the Alaska Range has witnessed no intense folding, though there may have been slow regional elevation as late as the end of the Tertiary period.

Pleistocene events in this region comprised mainly the waxing and waning of several stages of glaciation. At least twice during Pleistocene time, and possibly four or five times in all, glacial ice accumulated to great depth in this part of the Alaska Range, filling the valleys to depths as great as 2,000 feet or more and leaving only the higher peaks and ridges projecting above its surface. In their slow movement down the valleys the thick glaciers, shod with abundant rock fragments, exerted a powerful sculpturing effect on the underlying rock floor and developed the characteristic glaciated forms now everywhere recognizable. During their last retreat they left behind extensive deposits of morainal material and of outwash gravel, and the glacial remnants now left in so many of the valley heads are continuing in a minor way the same processes of erosion and deposition that so conspicuously characterized the far greater Pleistocene glaciers.

Since the last retreat of the ice from much of the region the streams have been engaged in reestablishing grades adjusted to their volume and load, and the normal processes of erosion and removal of waste in a subarctic climate have been resumed.

STRATIGRAPHY

BIRCH CREEK SCHIST

Character and distribution.—The Birch Creek schist occupies a narrow belt near the north border of this area (pl. 4), extending from the area east of the Nenana River in a west-southwest direction to Stony Creek, beyond which the schist area expands to include a large portion of the Kantishna Hills. Southeast of the McKinley Fork of the Kantishna River it apparently strikes off into the unsurveyed lowlands there, though quite likely it may there be in large part covered by younger rocks and by alluvium. East of this area the schist extends continuously to and beyond the Delta River and there forms a large part of the north slope of the Alaska Range.

The Birch Creek schist of the Alaska Range has been described by Brooks,[12] Prindle,[13] and Capps,[14] and from their descriptions it is apparent that the formation as a whole is of uniform appearance and composition over wide areas and can be readily identified in the field, although it includes several rock types. The most abundant phases consist of highly foliated and contorted fissile mica schist, quartzite schist, and phyllite in shades of green, red, brown, and gray. The readiness with which these rocks split into fissile slabs and flakes depends in considerable degree upon the extent to which they have been exposed to weathering. On slopes that have long been exposed to the weather the schist breaks down readily into thin slabs and plates of red or brown color and further disintegrates into quartz grains and mica flakes. By contrast, in recently cut canyons and in the beds of rapidly eroding streams the schist is much more massive and breaks into blocky slabs, and its prevailing color is green. These little-weathered greenish rocks are in many places so full of mica scales that the rock has a glistening silvery appearance. In places also the schist is highly garnetiferous, and the stream gravel from those areas contains large quantities of garnets

[12] Brooks, A. H., The Mount McKinley region, Alaska, with descriptions of the igneous rocks and the Bonnifield and Kantishna districts by L. M. Prindle: U. S. Geol. Survey Prof. Paper 70, pp. 56–60, 1911.

[13] Prindle, L. M., The Bonnifield and Kantishna regions: U. S. Geol. Survey Bull. 314, p. 206, 1907.

[14] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, pp. 20–22, 1912; The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 26–29, 1919.

the size of peas. Although the type phase of this schist is a highly fissile micaceous schist, the degree of schistosity differs greatly from place to place, and there are local areas of quartzitic rocks which are fairly massive and in which the cleavage is not well developed. They grade from nearly pure mica-free quartzite through micaceous quartzite in which there is a fairly well developed cleavage to highly fissile micaceous quartzite and mica schist. As in all schists, the mica plates are oriented in parallel planes, and the cleavage is in large measure due to the readiness with which the mica crystals split. In places a small amount of crystalline limestone is associated with the mica schist, and the Birch Creek schist as a whole probably consisted originally of a series of sediments including mudstone, sandstone, and a little limestone, into which were intruded igneous rocks of different types, both the sediments and the igneous rocks having later been metamorphosed to schist by burial and repeated folding and plication during the several periods of deformation to which the region has been subjected. As much of that deformation has followed lines parallel with the trend of the Alaska Range, the general strike of the schistosity is also in an east-northeast direction. The close crumpling of the schist, however, gives all possible dips within short distances.

Within the area mapped as Birch Creek schist on Plate 4 there are also igneous rocks of a wide range of texture and composition that were either laid down as lava flows interbedded with the sediments during their deposition or were intruded into the sediments at some later time. The igneous rocks range in composition from basic greenstone and hornblende schist to acidic intrusive rock and in texture from fine-grained to coarsely crystalline rocks. They also differ greatly in the amount of metamorphism which they have undergone. Some are so completely altered and deformed that their original character is difficult to determine, and they appear to be as old as the inclosing schist. Other intrusive bodies appear fresh and unaltered and were certainly intruded at a relatively late date, after the schist had been changed to its present condition. These facts indicate that the schist has been intruded at different times and by rocks of different kinds, and these igneous intrusions and flows have been so kneaded into the materials of sedimentary origin that their separation on a geologic map would require much more detailed work than has so far been possible. They are therefore grouped with the altered sediments on the map.

The schist is cut by many quartz veins and stringers, which tend to follow the foliation of the schist, though some cut across the foliation. Some appear to have been little or not at all deformed since their deposition; others have certainly been folded and sheared along with the inclosing rocks. It thus appears that the formation of veins in the schist has taken place at more than one time, some veins being very old and others relatively young. The numerous quartz gash veins and those veins that have been contorted and broken during the metamorphism of the schist are in general little mineralized. They consist prevailingly of milky-white massive quartz, slightly stained by the oxidation of metallic sulphides. At a few places a little scattered pyrite was observed in them. In addition to the gash veins that follow the planes of schistosity there are in certain areas, particularly in the Kantishna district, younger quartz veins, some of them many feet thick, that cut across the foliation of the schist and show no signs of having been folded with the inclosing country rock. Some of these veins have been traced along the surface for several hundred feet, and throughout their exposed length they maintain rather constant strike and dip. Furthermore, they are much more generously mineralized than the older, distorted veins and in places show abundant sulphides, the commonest of which are pyrite, arsenopyrite, sphalerite, galena, and stibnite. Less abundant minerals are scheelite, free sulphur, melanterite, pyrargyrite, scorodite, stephanite, stromeyerite, freibergite, bournonite, and gold, as well as antimony ochers, stibiconite, and kermesite. These veins have been extensively prospected at Mount Eielson and in the Kantishna district, where veins containing encouraging amounts of gold, silver, lead, zinc, and antimony have been found, and a considerable tonnage of ore valuable chiefly for its silver and lead content has been mined and shipped. These veins may be termed fissure veins, in contrast to the older contorted gash veins, and were formed much later than the gash veins, after the metamorphism of the inclosing schist was completed. They are believed to be of deep-seated origin and probably are genetically related to the intrusion of igneous rocks.

Some pyrite is scattered throughout the schist itself, and the oxidation of such finely disseminated pyrite no doubt yields the red and brown colors that the schist assumes on weathering.

Structure and thickness.—The schist has been formed by the deep burial and repeated and severe folding, crumpling, and recrystallization of a thick series of sediments and of minor amounts of associated lava flows and intrusive rocks. As a result of the very nature of these processes that have developed mica schists from previously unaltered sediments, the structure of the schist as a whole is exceedingly complex. Metamorphism has destroyed in large measure the original character of the beds, bedding planes are difficult to distinguish, the original beds have been squeezed thin in some places and greatly thickened in others, and the only obvious structure left is that of the planes of schistosity, which may depart widely from the original bedding planes. Furthermore, intricate and close folding and faulting tend to reduplicate the same bed many times in a single exposure. Individual observations on the strike and dip of the schistosity at isolated localities mean little, for although there is a general tendency for the planes of schistosity to strike in an east-northeast direction, parallel to the trend of this part of the Alaska Range, all possible dips may be observed within an area of a few square feet. The thickness of the schist series can not even be estimated with any confidence. These rocks are the oldest exposed in this region, and therefore their base has not been observed. However, mountains composed entirely of Birch Creek schist show these rocks through a vertical range of more than 3,000 feet, and in the Kantishna Hills, a region of high relief, these rocks occupy an area of many hundreds of square miles. It therefore seems unlikely that the schist is less than 3,000 to 4,000 feet thick, and it may be much thicker.

Origin.—The materials of which the Birch Creek schist is composed were no doubt originally for the most part clastic sediments, including shale, sandstone, and a little limestone. The quartzitic beds represent original quartz sandstone, some carbonaceous slate is the altered equivalent of shale, and the crystalline limestone represents the remains of marine lime-secreting organisms. All these rocks contain mica and other secondary minerals. In addition to the altered sediments there are certain rocks that with little doubt are of igneous origin, such as greenstone schist and gneiss, and still others that are less completely metamorphosed than the inclosing sedimentary materials and retain enough of their original character to show conclusively that they are of intrusive origin. The schist, as a whole, therefore consists mostly of altered sediments, with minor amounts of rocks of igneous origin.

Age and correlation.—Although the Birch Creek schist has been studied over a wide area and by many observers, positive evidence of its age is still lacking. It has yielded no fossils, and none are to be expected in it. Furthermore, the schist is the oldest rock exposed in this region, and nothing is known of the materials that underlie it. What are considered to be the next younger rocks—the slate, limestone, serpentine, and schist that occur just north of the great fault—are also of unknown age, though they are known to underlie another thick group of sediments that include limestone of Middle Devonian age. In this region, therefore, the only positive evidence that has been obtained is that the schist is considerably older than Middle Devonian. By correlation, however, a closer age assignment can be made. The schist first described by Spurr,[15] from the type

[15] Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 140, 1898.

locality in the Yukon-Tanana region, is nearly identical in character with that in the Alaska Range, and the correlation of the Birch Creek schist in these two areas seems to be sound. The schist in the Yukon Basin was considered to be of pre-Ordovician age,[16] and that age determination was the best available for many years, though increased knowledge of the section there seemed to indicate that the schist was considerably older than the Ordovician. More recent studies in the upper Yukon Basin in Alaska by Mertie[17] have convinced him that the Birch Creek schist is definitely pre-Cambrian, and for the present that must remain as the most accurate age assignment that can be made.

SCHIST, SLATE, LIMESTONE, AND SERPENTINE GROUP

Character and distribution.—In the headward basins of the Bull and Cantwell Rivers and Windy Creek, immediately north of the great fault and occupying a narrow belt along it, is a series of highly metamorphic rocks including slate and slaty schist, serpentine, crystalline limestone, and various igneous rocks in different stages of metamorphism. These rocks lie beneath the basal portion of the sedimentary series that contains Middle Devonian limestone, and they are therefore the oldest rocks that appear on the south slope of the Alaska Range in this region. This series includes greenstone, fairly massive in places, which grades into greenstone schist, and that in turn into serpentine, below which lie red, green, and purple rocks that include shale, sandy shale, and sandstone, and these grade into thin-cleaving sandy slate and glossy wavy slate, and thence into schist and phyllite. All the colors shown by these rocks are apparently the result of some change that has occurred in them during their metamorphism, for single exposures exhibit a mottled, patchy arrangement of these colors, the color patches apparently having no definite relation to the original bedding. Still lower in the series there is a limestone, intricately fractured and completely recrystallized, that ranges from 30 to 200 feet in thickness.

The belt in which these rocks occur is narrow and in places had to be somewhat exaggerated in width in order to show on a map of the scale of Plate 4. The maximum thickness of this group of rocks as exposed on the Bull River is only 200 to 300 feet, though on Windy Creek and the Cantwell River the group is probably several times that thick. These materials were brought up along the upthrown side of the great fault, and apparently the relative displacement along that fault was not great enough, west of the Bull River, to expose

[16] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, pp. 264–271, 1908.

[17] Mertie, J. B., jr., Geology of the Eagle-Circle district, Alaska: U. S. Geol. Survey Bull. 816, pp. 17–20, 1930.

them, although possibly some of the crushed rocks in the fault zone in the basin of the West Fork of the Chulitna River may belong to this group. In most places, indeed, the most readily recognizable rocks of this group are the characteristic wavy red slaty schist and the serpentine, though these were not observed west of Easy Pass. However, as all the rocks along the fault zone, from Paleozoic to Tertiary, are locally crushed and sheared until even the Tertiary conglomerate is in many places schistose, it is difficult to select any plane of demarcation which can be regarded with confidence as separating the Devonian and associated sediments from the underlying pre-Devonian materials, and it is possible that some beds of the older group may have been here included with the younger. Localities at which the rocks within the fault zone are well exposed are rare, for the crushed and schistose rocks in that zone are weak and form a series of depressions and passes in which exposures are poor or lacking. Yet the conspicuous wavy red slate was traced, either in observed outcrops or by abundant surface float, from a point about 3 miles east of Easy Pass across the upper Cantwell Basin to and beyond Windy Creek. The area along the fault between Windy Creek and the Nenana River was not examined, and this group of rocks was not mapped there, though very likely it may be present.

Structure and thickness.—Throughout the portion of the great fault in this region that has been closely examined, from the area near Anderson Pass eastward to Windy Creek, a distance of over 30 miles, the fault plane stands vertical or nearly so, and the bedding of the materials within the fault zone, both on the southern, downthrown side and the northern, upthrown side, is also approximately vertical and parallel with the fault plane. All the materials within the fault zone, which is in places many hundreds of feet wide, show some degree of schistosity, and certain shale beds are crushed and pulverized to clay and fine fragments, whereas more competent beds of conglomerate are stretched and schistose. Yet, in spite of the fact that all beds in the fault zone are more or less sheared, nevertheless the more competent beds, such as conglomerate and graywacke, resisted shearing, and the less competent shale and slate yielded more easily, so that most of the displacement took place by yielding and slipping within beds of shale or slate. For about 15 miles along the fault, from a point 3 miles east of Easy Pass to the western fork of Windy Creek, a narrow belt of the slate schist and serpentine group only a few hundred feet thick appears along the upthrown side of the fault, a fact which indicates that these rocks yielded more easily to faulting than the overlying conglomerate, graywacke, and limestone group and so localized the zone along which much of the displacement took place. The structure of this serpentine, slate, and limestone group, for a considerable part of the area in which it is exposed, is that of a plate only a few hundred feet thick that stands nearly vertical or has a steep dip to the north, parallel to the plane of the fault zone. Farther east, in the basin of Windy Creek, a thicker section, perhaps 1,000 feet thick, of the same rocks dips 50°–70° S. There it is apparent that these rocks lie unconformably beneath the Devonian and associated rocks, and it is probable that the two groups are generally separated by an angular unconformity.

Age and correlation.—There is still considerable uncertainty about the exact age of this group of rocks. In degree of metamorphism the materials appear to be younger than the Birch Creek schist, though the most exact age determination of the Birch Creek that can yet be made is that it is pre-Cambrian. On the other hand, this group of slate, shale, serpentine, and limestone definitely underlies the group of sediments described on pages 251–255 that contains in its upper part Middle Devonian fossils. That group, however, may well include rocks that are considerably older than Middle Devonian. These metamorphic rocks are therefore intermediate in age between the pre-Cambrian Birch Creek schist and the group a part of which is Middle Devonian. They are less metamorphosed and therefore presumably considerably younger than the Birch Creek but more highly metamorphosed and therefore presumably considerably older than the Middle Devonian. No more accurate age assignment is now possible, and the rocks are therefore here tentatively assigned to the pre-Devonian part of the Paleozoic.

UNDIFFERENTIATED PALEOZOIC ROCKS

Character and distribution.—On the north flank of the Alaska Range, extending from the basin of the Sanctuary River westward to the basin of Stony Creek, there are certain metamorphosed sedimentary rocks that occur in narrow bands that follow the trend of the Alaska Range. These rocks are described by Brooks [18] as the Tatina and Tonzona groups, for he correlated them with rocks mapped and named in the basins of the Tatina and Tonzona Rivers, 125 and 90 miles, respectively, southwest of the westernmost outcrop of these rocks in the region here under consideration. Capps [19] also described these same rocks in the basins of the Toklat and Teklanika Rivers, and although he there obtained no definite evidence of their age, he followed Brooks in correlating them with the Tatina and Tonzona groups. Later studies, however, have shaken his confidence in the soundness of these long-range correlations. The rocks

[18] Brooks, A. H., op. cit., pp. 69–73.

[19] Capps, S. R., The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 29–34, 1919.

of these two groups include shale, slate, argillite, sandstone, graywacke, thin-bedded limestone and chert, together with associated igneous rocks that have been metamorphosed to gneiss. They are all cut by multitudes of quartz and calcite stringers. The counterpart of any of these rocks, with the possible exception of the gneiss, both as to composition and as to degree of metamorphism, may be found in the group of Devonian and associated rocks or in the Mesozoic rocks on the south flank of the range. These resemblances weaken the correlation with beds far to the southwest, and the writer here abandons any definite correlation of these rocks and groups them for convenience as of undifferentiated Paleozoic age, with the reservation that they may also include Mesozoic materials. As these rocks are of highly complex structure and have been studied only during hasty reconnaissance mapping, their differentiation must await more detailed study.

The descriptions of these rocks by the writer as Tatina group and Tonzona group, above cited, are as complete as present knowledge warrants, and they will not be repeated here.

Structure, thickness, and age.—The structure of this group of rocks is so complicated by large folds, close crumpling, and faulting that little can be said except that there is here a highly metamorphic group of sedimentary rocks that in general strike east-northeast, parallel with the trend of the range, and dip at high angles. They are bordered on the north by the Birch Creek schist, which is older and dips unconformably beneath them, and are in part overlain unconformably by the Cantwell formation. The linear shape of their surface outcrops is apparently the result of fairly close folding, the Cantwell beds having been stripped off of the crest of the folds.

It is quite possible that this undifferentiated group of sediments includes rocks of a wide range in age. Brooks and Capps noted the resemblance of certain constituents to rocks of the Tatina group, which Brooks found to be, in part at least, of Ordovician age. Certain other rocks were thought to be correlatives of the Tonzona, which Brooks tentatively assigned to the Silurian or Lower Devonian, though he had no unquestionable evidence for that assignment. In the midst of rocks previously assigned by Brooks to the Tonzona the writer found a few imperfect corals that resembled Mesozoic types and that were thought to be of probable Triassic age. Later studies showed wide areas of similar sediments in the Alaska Range, equally metamorphosed, that are certainly of Mesozoic age. It therefore seems best for the present to group together these rocks as an undifferentiated group of sediments which are younger than the pre-Cambrian Birch Creek schist but older than the Tertiary Cantwell formation and which are probably mainly of Paleozoic age but possibly include also considerable Mesozoic material. The final differentiation of this group must await more detailed field studies than have yet been made.

MIDDLE DEVONIAN AND ASSOCIATED SEDIMENTS

Character and distribution.—Along the crest of the Alaska Range, extending from Muldrow Glacier eastward to and beyond the Nenana River, there is an area occupied by a thick series of metamorphosed sedimentary rocks that includes conglomerate, shale, slate, graywacke, quartzite, and thin-bedded and massive limestone. In the area west of the Nenana River all these rocks lie north of the great fault and in fact are bounded by that fault for considerable distances. East of the Nenana River they lie south of the great fault. To the north this series of sediments is overlain and thus obscured by late Paleozoic or early Mesozoic greenstone and by the Tertiary Cantwell formation or is bordered by intrusive rocks. The belt in which these rocks occur is widest at its west end, between Muldrow Glacier and the Toklat River, and narrows to the east toward the Nenana River. This distribution, however, is not entirely due to the amount of displacement along the great fault, for from Anderson Pass eastward to and beyond Easy Pass the underlying slate, schist, serpentine, and limestone series is not brought to the surface, whereas farther east, where the belt of Middle Devonian and associated sediments is narrower, the deeper underlying beds come up along the fault. At the point where the Nenana River crosses the great fault the distribution of the rock formations indicates that the fault displacement is very small, and east of the river the surface distribution of the rocks suggests that the relations of the two sides of the fault are reversed and that there the north side is the downthrown side and the south side the upthrown side.

In general, the oldest exposed portion of this series, in any north-south section across the range, occurs at the south edge of its outcrop, adjacent to the great fault. From Anderson Pass eastward to the headward basin of the Bull River the fault fails to bring the base of this series to the surface, but from a point near Easy Pass eastward to Windy Creek the fault exposes the series to its base and also a portion of the underlying slate, schist, serpentine, and limestone series. Even where the base of the series is exposed, however, the section differs greatly from place to place, owing in part to the severe metamorphism, with its close folding and faulting, and in part to the fact that the sediments laid down at any one time differed in character and in thickness from place to place. In general, however the lowest portion of the series where its base is exposed is composed of massive dark-brown to black conglomerate that ranges from 200 to 1,000 feet or more in thickness. This conglomerate ranges in texture from coarse grit to conglomerate in which pebbles 6 inches in diameter are common. Most of the pebbles are of black chert and argillite, with some pebbles of quartz and light-colored chert and other types of rock, all set in a matrix of more finely comminuted materials of the same sort. The conglomerate is much more massive than the overlying sediments of this series, probably because of its greater competence, for it has resisted shearing and close folding more completely than the thin-bedded slate, argillite, and limestone and has also been more resistant to deformation than the heavy limestone of the series. The conglomerate, though generally free from schistosity, is nevertheless much fractured, and many of the fractures are filled by thin veinlets of quartz or calcite.

Immediately above the dark, massive basal conglomerate there occurs in places a bed 50 to 200 feet thick of a hard white conglomerate, in which the pebbles, generally 2 inches or less in diameter, are composed mainly of white quartz, in a white or gray siliceous matrix. This conglomerate also has been more resistant to metamorphism than the thin-bedded sediments immediately above it.

Above the conglomerate lies a series of beds several thousand feet thick, composed of alternating layers of black slate or argillite and graywacke or quartzite that exhibit varying degrees of schistosity. These beds are characterized by the rusty red hue they have taken on where they have been at all weathered. Freshly broken faces fail to show this rusty color, but all joint cracks and weathered surfaces exhibit it, and in the great cliff-like exposures of these rocks in the steep valleys and gulches just north of the great fault the reddish color is conspicuous and characteristic. Apparently the color is due to the oxidation of finely disseminated iron pyrite. Freshly broken and unweathered surfaces show the slate and argillite to be black and the graywacke and quartzite gray. In addition to the prevailing argillite, slate, graywacke, and quartzite some sections also contain hard, siliceous conglomerate, thin-bedded black limestone, and in places black or gray limestone beds that reach a maximum thickness or 20 or 30 feet. All these rocks are abundantly seamed with quartz veins that attain 3 or 4 feet in thickness and show reticulating veinlets of calcite.

Upward in the section there is a more or less gradual transition from the argillite, slate, graywacke, and quartzite into a more limy phase. Thin-bedded limestone is interbedded with the clastic sediments, and the limestone beds become more and more abundant, until in places the limestone equals or surpasses in amount the associated clastic sediments. Some of the thin limestone beds are gray when weathered but on freshly broken surfaces are black and contain considerable argillaceous material. Other beds consist of fairly pure limestone. In general, the portion of the section in which the thin-bedded limestone occurs is much crumpled and folded, the limestone is recrystallized, and limestone, slate or shale, and graywacke are intricately cut by veinlets and stringers of calcite and quartz. Still higher in the section, above the thin-bedded limestone and associated clastic sediments, there is in places a massive gray recrystallized limestone that locally reaches a thickness of 1,500 feet, though it is generally not so thick. This massive limestone was found to be practically continuous from the eastern head of the Bull River eastward to the west fork of Windy Creek. West of this belt it was not observed on the south flank of the range, but as the limestone everywhere lies near the crest of the range, at the head of the many glaciers that flow both north and south from the main divide, it was not possible in the time available to map the borders of the limestone in detail, and it may be present in some areas that were not mapped.

On the north flank of the range, in the basins of the glaciers that drain to the Sanctuary, Teklanika, and Toklat Rivers, there are disconnected patches of massive limestone that may be the stratigraphic equivalent of the limestone just described or may be another limestone lying higher in the series. The numerous limestone outcrops on the north slope of the range, though probably belonging to the same stratigraphic horizon, are discontinuous in outcrop as the result of complex folding and faulting. In general, they are recrystallized and devoid of fossils, but in one locality they have yielded fossils of Middle Devonian age.

The complex structure of this whole series and the rugged glacier-filled area in which it occurs have prevented as thorough a study of these rocks as they deserve, and much remains to be learned about them. The information now at hand, however, indicates that stratigraphically above the massive limestone lies several thousand feet of black slate, chert, and thin-bedded limestone, cut by diorite intrusions.

In certain parts of the region, particularly between Muldrow Glacier and the Toklat River and including Mount Eielson, the thin-bedded limestone, shale, slate, and graywacke or quartzite are so intimately cut by granitic intrusive rocks that in places the intrusive material actually exceeds in amount the sediments into which it was injected. These intrusive rocks form sills, dikes, and irregular masses of various shapes but in general have followed the strike of the bedding and are therefore longest in a direction parallel to the structure of the range. They forced their way into the sedimentary series in part by crowding the sediments aside but possibly also to some extent by dissolving and incorporating into the intrusive mass the more easily digestible of the sediments. It is in the limy beds near these intrusive rocks that the sulphide ores of Mount Eielson occur. On the accompanying map those areas of Devonian and associated sediments that are most intricately intruded by granitic rocks are shown with a separate pattern.

Structure and thickness.—The structure of this group of Paleozoic sediments is highly complicated. The beds have been folded, faulted, crumpled, and metamorphosed, probably at several different times, and the result is a complex, the details of which have not yet been worked out. Along the north border of the great fault the beds are especially mashed and sheared, and although most of the displacement in the fault zone is believed to have taken place in the less competent beds of the Cantwell formation and the underlying schist group, nevertheless some of the shearing was distributed in the group of Middle Devonian and associated sediments.

Commonly the sediments show some schistosity, differing in degree from place to place. The graywacke and quartzite range from massive rocks to more schistose phases in which the development of secondary mica gives definite cleavage planes. The argillaceous beds in many places form well-developed slate, in which the cleavage planes cross the planes of bedding. Some beds are thin-cleaving, roofing-slate types; others break down into prisms within which the lines of schistosity are finely crenulated. Conglomerate beds, particularly the heavy basal conglomerate, have resisted metamorphism more successfully than the other sediments, but they are locally mashed and stretched and in places have become chloritic schist that is difficult to recognize as having once been a conglomerate. Other conglomerate beds have been silicified by the replacement of the matrix of quartz. The limestone is commonly recrystallized, and some beds are now composed largely of secondary white calcite. In places a pink crystalline limestone occurs, and elsewhere the limestone consists of alternating contorted bands of black limestone and white calcite, reticulated by calcite veinlets.

So far as its highly complex structure has been deciphered, this series seems to have a general strike parallel with the trend of the range and to have a prevailingly northward dip. This attitude results in the oldest beds of the series appearing just north of the great fault and successively younger beds being encountered toward the crest of the range. The possibility of these beds forming a broad synclinal trough is suggested by the occurrence of two bands of massive limestone in the section south of the Sanctuary and Teklanika Basins. The identity of these two limestones has not been established, however, and the general dip of the beds is, so far as known, northward across the entire section, so that the beds appearing on the north flank of the outcrop probably represent the youngest portion of the series. These beds are overlain by greenstone of Paleozoic or Mesozoic age and by the Tertiary Cantwell beds. On the West Fork of Windy Creek, where the massive limestone has an apparent thickness of at least 1,500 feet, the dips approach the vertical, and there is much evidence of close folding, so that it is quite possible that this unusual thickness of massive limestone includes both limbs of a closely compressed fold.

Only a very general estimate can now be made of the thickness of this series. The maximum thickness of the different members would include 1,000 feet or more of basal conglomerate, 3,000 feet or more of slate, shale, graywacke, and quartzite, 2,500 feet of slate, graywacke, and thin-bedded limestone, 1,500 feet of massive limestone, and 2,000 feet of black slate and chert, or a total thickness of about 10,000 feet. Too great reliance should not be placed upon this figure, as much more field work will be necessary before an accurate estimate can be made, but it serves to indicate that this is a tremendously thick series of Paleozoic sediments. No doubt this series will eventually be subdivided into a number of smaller units.

Age and correlation.—The sediments of this group are so poorly supplied with fossils that no adequate statement can now be made of the time range covered by the group as a whole. A careful search made along the south flank of the range between Anderson Pass and Windy Creek failed to discover a single fossil. In 1913, however, in the lower valley of the Jack River, Moffit [20] collected fossils that were identified as of upper Middle Devonian or lower Upper Devonian age from beds which are believed to belong to this group. In 1919 the writer collected fossil corals that were determined to be clearly of Middle Devonian age from a limestone at the head of the Middle Fork of the Sanctuary River. These two collections comprise the entire paleontologic evidence so far obtained from this great group of beds. Both collections were obtained from limestone, and both indicate a Devonian age for these beds. The group as a whole, as here defined, includes, however, great thicknesses of beds that lie stratigraphically both above and below the horizons at which limestone occurs. There is no assurance that the group may not include some beds older than Devonian and some younger. All that can now be said is that it is of Paleozoic age, contains Middle Devonian limestone, and also contains thick sediments lying both above and below the Middle Devonian limestone.

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[20] Moffit, F. H., The Broad Pass region, Alaska: U. S. Geol. Survey Bull. 608, pp. 25–26, 1915.

LATE PALEOZOIC AND EARLY MESOZOIC GREENSTONE

Character, distribution, and age.—Although the intrusive igneous rocks of this region are discussed in another part of this report, certain basic lava flows on the north flank of the range between Muldrow Glacier and the East Fork of the Toklat River have a definite stratigraphic position and are therefore here included in their chronologic order with the other bedded rocks.

These rocks, which fall under the broad description of greenstone, include mainly amygdular lavas, some of which show ellipsoidal structure. Their bedded character and the presence of abundant amygdules indicate that they were poured out on the surface as lava flows, but the ellipsoidal structure of some beds suggests that they were laid down under water. The prevailing colors are various shades of dark green, brown, and purple. In general there is little sedimentary material interbedded with the lava flows, and no fossils have been found in them.

South of the crest of the Alaska Range greenstone and greenstone tuff, with associated slate and chert, occur just west of Cantwell and also west of the Chulitna River on Long, Copeland, and Ohio Creeks, south of the area here considered. These rocks apparently occupy about the same stratigraphic position as the amygdular and ellipsoidal greenstones between Muldrow Glacier and the East Fork of the Toklat River and are here correlated with them.

As these lavas and tuffs have yielded no fossils, their age can be determined only by their stratigraphic relations to older and younger rocks of known age and by suggested correlation with similar rocks elsewhere in Alaska, the age of which is better known. In this region the greenstone overlies and is therefore younger than the Middle Devonian and associated sediments. As that group may contain beds considerably younger than Middle Devonian, the lower age limit of the greenstone is not definitely known. South of this region, in the basin of the Chulitna River, some of the greenstone definitely underlies beds that carry Triassic fossils and is therefore either early Triassic or pre-Triassic. North of the range, in the Toklat Basin, the greenstone flows are overlain by the Cantwell formation, of Eocene age.

Although conclusive evidence of the age of the greenstone has not been found in this region, the above facts suggest that it is of late Paleozoic and early Mesozoic age. In the Broad Pass region Moffit [21] described similar greenstone that he tentatively classified as Triassic. In the upper Nizina region of the Wrangell Mountains Moffit [22] de-

[21] Moffit, F. H., op. cit., pp. 26–28, 1915.
[22] Moffit, F. H., Notes on the geology of upper Nizina River, Alaska: U. S. Geol. Survey Bull. 813, pp. 147–154, 1930.

scribes great thicknesses of greenstone flows with some of which there are interbedded limestone beds that carry Permian fossils. Other flows, the Nikolai greenstone, underlie Upper Triassic limestone, but Moffit is inclined to believe them to be of Permian age also. It is quite possible that the greenstone flows and tuffs of the region here described correspond in age with the Permian greenstone of the Wrangell Mountains, but this is not yet proved. For the present it seems best to leave their age assignment indefinite, with the probability that they are of late Paleozoic and early Mesozoic age.

TRIASSIC ROCKS [23]

Character and distribution.—The rocks here grouped as Triassic occur in the southern part of this region, in the basins of the West Fork of the Chulitna River and Long and Ohio Creeks. Where they are crossed by the West Fork of the Chulitna they occupy a belt 6 miles wide from north to south. To the southwest these rocks extend into unsurveyed territory southwest of Ohio Creek, and to the northeast they plunge beneath the surficial, glacial, and stream deposits of the Broad Pass depression. To the southeast the Triassic rocks are bordered by older metamorphic materials that include greenstone tuff, slate, and chert, whose age is not accurately known. To the northwest they are overlain by a thick group of Jurassic or Cretaceous shales.

The Triassic rocks comprise a group of sediments having a wide range of character and composition. Most abundant are argillite, slate, and hard impure sandstone or graywacke, but there are also numerous beds of conglomerate, tuff, black chert, and limestone, all cut by dikes and sills of both acidic and basic rocks. On upper Ohio Creek these sediments are interbedded with amygdaloidal greenstone flows. The whole series is so intricately crumpled, folded, and faulted in the section on the West Fork of the Chulitna River that it is at present impossible to construct a columnar section giving the position and thickness of the different members at that place. The Ohio Creek section, which has been examined only hastily, appears to be less disturbed, and there the basal member of the Triassic, a heavy bed of red tuff and agglomerate, lies apparently unconformably upon the pre-Triassic greenstone tuff, slate, and chert. Above the tuff and agglomerate is a group of rocks several thousand feet thick that includes tuff, agglomerate, conglomerate, amygdaloidal greenstone flows, and massive limestone beds.

[23] Since this report was written more detailed study by C. P. Ross in the basin of the Chulitna River has disclosed the presence of fossils of Carboniferous age in rocks here mapped and described as Triassic. Unquestioned Triassic rocks are present, however, but as here described they include also some older materials.

The prevailing Triassic rocks, as exposed on the West Fork of the Chulitna River, consist of mudstone that now ranges in character from hard argillite and shale to slate and gray impure sandstone so indurated that it approaches quartzite in hardness. These impure arenaceous rocks are described under the general designation graywacke. The proportion of shale, argillite, and slate to coarser-grained graywacke differs greatly from place to place. In some localities beds several hundred feet thick are composed almost exclusively of graywacke. These may be succeeded by a group of strata in which beds of shale or argillite a foot or so thick alternate with graywacke beds of similar thickness, and these in turn may be followed by 100 feet or more of argillite or shale in which there is little interbedded graywacke. There are also beds of all degrees of fineness, from very fine grained mudstone through arenaceous shale to argillaceous graywacke, and these grade from fine grained through coarse sandy beds to grit and conglomerate. Interspersed with the shale, slate, argillite, and graywacke there are locally some beds of dense black chert.

The conglomerate and tuff also show a wide range in texture and composition. The tuff ranges in texture from a fine-grained rock that resembles red sandstone, through coarser rocks composed of angular fragments from one-eighth to 1 inch in diameter, to coarse agglomerate that contains fragments of volcanic débris several inches across. The tuff ranges in color from vivid red, in which the composing fragments are chiefly jaspilite, to green and purple. In some of the tuff the fragments all appear to be sharply angular in outline; in other beds some fragments are angular and others partly rounded. The tuff grades, by scarcely perceptible variations, into rocks composed largely of beautifully rounded quartz pebbles the size of peas, so that characteristic tuff and typical conglomerate are apparently connected by a series of intermediate rocks.

In the section exposed on and northeast of the West Fork of the Chulitna River limestone is present only in small amounts, and exposures are rare. It can best be seen in the excavations made on a mineralized zone at the Riverside group of claims, 2 miles west of the mouth of Colorado Creek. There the thickness of the limestone, which is extensively intruded by dike rocks, could not be determined, the limestone being completely recrystallized and in part being replaced by intrusive rocks and vein material. Farther southwest, on Ohio Creek, the basal portion of the Triassic group includes agglomerate, tuff, and greenstone flows interbedded with which are five distinct zones of massive limestone.

Within the area on the north flank of the range that is shown on Plate 4 as composed mainly of undifferentiated Paleozoic rocks a fossil coral was collected by the writer and was determined as of probable Mesozoic age, though no closer assignment was made. These metamorphic rocks therefore probably include materials of Mesozoic as well as of Paleozoic age, though whether these Mesozoic materials are Triassic or younger is not known. Elsewhere in the region massive Mesozoic limestone beds are known only in the Triassic, and this suggests that some Triassic rocks may be included in the group of undifferentiated metamorphic materials on the north flank of the range.

Structure and thickness.—Too little study has yet been given to this group of Triassic rocks to yield an accurate measure of its thickness. Everywhere there is evidence of crumpling and mashing, of large and small folds, and of faulting. The general strike of both the bedding and the folds is northeast, and the prevailing dips are steep and to the northwest. There are, however, numberless localities at which the strike both of the beds and of the minor folds departs widely from the general northeast trend, in places as much as 90°, and dips to the southeast are not uncommon. The recurrence of the peculiar tuff or conglomerate composed of red jasper pebbles in a red sandy matrix at localities 2 miles apart across the strike, on the West Fork of the Chulitna River, indicates the probability that the beds are duplicated either by faulting or folding. Other duplication elsewhere in the monotonous succession of argillite, slate, and graywacke beds might easily escape observation in any but the most detailed study.

As a result of the complex structure, close folding, crumpling, and faulting, as well as the uncertainty concerning the line of demarcation between the Triassic rocks and the overlying shale series, it is obviously impossible to make an accurate estimate of the thickness of this group of sediments. On the southwest side of the West Fork of the Chulitna River, which cuts at an angle across the strike of this group, the steeply dipping beds are present for a distance of about 8 miles. It is therefore apparent that even allowing for much reduplication by faulting and folding, the group must include several thousand feet of beds. No closer estimate of its thickness can now be made.

Age and correlation.—The age determination of this group of rocks is based largely on the evidence of fossil collections made by the writer on Copeland and Ohio Creeks in 1917, from a limestone that is believed to be the equivalent of the unfossiliferous crystalline limestone on the West Fork of the Chulitna River, described above. These fossils were determined to be of Triassic age. The limestones on both Ohio and Copeland Creeks were associated with the same distinctive red and green tuff and conglomerate that occur on the West Fork of the Chulitna River, and there seems to be no reason to doubt that the limestone beds observed in three valleys along the same strike are identical, although the outcrop has not been traced continuously from one to the other. The fossil evidence is therefore positive that at least a portion of the series is of Triassic age. The age of the associated tuff, conglomerate, argillite, and graywacke above and below the limestone, however, is less certain. No fossils have been found in them. Indeed, the whole belt of Mesozoic sediments that extends along the southeast flank of the Alaska Range from Broad Pass southwestward through the Yentna district to the headward basin of the Skwentna River and thence diagonally across to the west flank of the range as far as Lake Clark is remarkable for its paucity of fossils. In the region here under consideration beds at only a single horizon in this group have yielded fossils, and there is therefore as yet no adequate basis for subdividing this thick group of rocks, although it contains such diverse materials. It can only be stated that some of the beds are older than the Triassic limestone and some younger. It is even possible, though not probable, that part of this group is of pre-Triassic age, and it is not at all improbable that beds as young as Lower Jurassic are included in it.

JURASSIC OR CRETACEOUS ROCKS

Character and distribution.—On the south flank of the Alaska Range in this region, extending from Windy Creek southwestward across the basins of the Cantwell and Bull Rivers, and the West Fork of the Chulitna, and thence southwestward into a rugged, unmapped portion of the range, there is a belt of rocks, from 4 to 6 miles or more wide, that is composed predominantly of mudstone, now indurated and metamorphosed into shale, argillite, and slate. This belt also includes many beds of impure arenaceous material or graywacke, some conglomerate, some black chert, and a very little black limestone in thin beds and lenses. As contrasted with the beds of the Triassic group, already described, which adjoin them on the southeast and underlie them structurally, the younger group of rocks is composed prevailingly of fine-grained mudstone which breaks down readily into thin slabs, prisms, and fine particles and which under the effects of erosion yields mountains of smoother topography and less precipitous cliffs and crags than the more competent graywacke, conglomerate, tuff, lava, and limestone of the Triassic group.

Besides the mudstone, which now forms shale, argillite, or slate, depending upon the amount of metamorphism that it has undergone, this group also contains minor amounts of black chert beds that may have been originally deposited as chert or that may have been silicified by the introduction of secondary silica and by its replacement of the original materials. Locally arenaceous shale and even fairly abundant thin-bedded graywacke are interbedded with the shale, and at intervals there are fine to moderately coarse conglomerates, the pebbles of which are mostly chert, argillite, and quartz. At one locality irregular lenses of dark-gray to black limestone a few feet thick and full of shell fragments were found, but as a rule limestone is very scarce, and the impression gained of the series as a whole is that of a group of rocks in which shale and argillite greatly preponderate over the other sediments, and graywacke, conglomerate, chert, and limestone are present in relatively small amounts, their abundance decreasing in the order named. The whole series is cut by dikes and sills of the same types of intrusive rocks as those which cut the Triassic rocks, though the Jurassic or Cretaceous rocks seem to have been less favorable host rocks than those of the Triassic, for intrusive material is less abundant in them. A few sills that weather to a conspicuous reddish color in contrast to the black shale follow the bedding for considerable distances, though they are nowhere of very great thickness

On the north flank of the range, in the basins of the Savage and Sanctuary Rivers, there is an area of black shale and slate that lie unconformably beneath the Cantwell formation and in many ways resemble the Jurassic or Cretaceous shale on the south flank of the range. Here the argillite and shale are highly distorted, having suffered close folding, crumpling, and faulting, and contain many quartz veinlets, some as much as 8 inches thick. No fossils were found in these beds, but their general character and their position immediately beneath the beds of the Cantwell formation suggest their correlation with the similar rocks on the opposite flank of the mountains.

Structure and thickness.—The Jurassic or Cretaceous shale is an incompetent rock as compared with both the graywacke, tuff, conglomerate, and limestone beds of the underlying Triassic rocks and with the massive conglomerate of the overlying Cantwell, and as the Jurassic or Cretaceous rocks are largely composed of shale, they have suffered accordingly in the general diastrophism of the region. Characteristically these beds of shale have a highly complex structure, being closely folded, crumpled, faulted, and mashed, and although their general structural trend is east-northeastward, parallel to the trend of the range, and the average dip is northwest, nevertheless there are many small areas in which strikes in any direction can be found and in which there is wide variation in the dip. In detail, therefore, the structure is so highly complex that it has so far not been feasible to trace out the course of individual beds, yet in general the strike is east-northeast and the dip rather steep to the northwest.

The structural relations between the Jurassic or Cretaceous rocks and the underlying Triassic group and the overlying Cantwell formation are not yet completely understood. In the almost complete absence of fossils in all these rock groups the main reliance of the stratigrapher in determining the boundaries of his subdivisions fails, and he is forced to rely on changes in lithology or on structural breaks to separate one rock group from another. In the region here under consideration no actual unconformity was recognized between the rocks grouped with the Triassic and those included in the Jurassic or Cretaceous group, although in general the Triassic rocks seem to be somewhat more severely metamorphosed. The Jurassic or Cretaceous group is composed predominantly of shale, argillite, and slate, whereas the Triassic group contains much coarser material. It is along the line where the prevailing alternation of shale, argillite, and graywacke gives place to a prevailing mudstone series that the boundary between the Triassic group and the Jurassic or Cretaceous group has been drawn. The Cantwell formation contains much shale and argillite, there being in places sections many hundreds of feet thick in which little or no coarse material occurs with the mudstone. This lithologic similarity between two adjacent rock groups makes it difficult to draw the boundary between them, and it is possible that in the Cantwell and Windy Creek Basins Cantwell rocks have been mapped with the Jurassic or Cretaceous group, or vice versa. In the upper basin of the West Fork of the Chulitna River, however, the Cantwell rocks seem in general to be less closely folded and crumpled than the underlying Jurassic or Cretaceous beds. In the Savage and Sanctuary Basins there is a sharper contrast in lithology as well as a definite angular unconformity between the shale group and the overlying Cantwell formation.

Like the Triassic group, the Jurassic or Cretaceous rocks are so intricately folded and faulted that no precise estimate of their thickness can now be made, yet they occupy a belt as much as 6 to 8 miles wide in a region of rugged mountains in which there is a vertical relief of as much as 4,500 feet. It is therefore difficult to imagine the structure that even with such intense folding and reduplication by faulting could give rise to so extensive an outcrop, in a region of such high relief, unless the rocks of the series were 4,000 to 5,000 feet thick, and the actual thickness may greatly exceed that amount.

Age and correlation.—The associated rock units on the south side of the great fault include the Triassic group, the Jurassic or Cretaceous group, and the Cantwell formation, all of which contain much shale, argillite, and slate, and these materials are very similar in appearance in all three rock units. As a consequence of this lithologic similarity, of the complex structure that involves all three groups, and of the paucity of fossils in all of them the determination of the boundaries between groups and of the age limits of the groups themselves is filled with uncertainties. In this region beds at only a single horizon in the Triassic group have yielded fossils, and at only one locality have fossils been found in the Jurassic or Cretaceous group. The stratigraphic position of these two horizons is probably several thousand feet apart. As already stated, the boundary here given between the Triassic group and the Jurassic or Cretaceous group has been drawn upon lithologic grounds, but possibly as drawn it is too high or too low in the section. Far up in the section, probably as much as 1,500 to 2,000 feet stratigraphically above that boundary, a single fossil collection was obtained, which was examined by T. W. Stanton, who determined it as "not older than Upper Jurassic and not younger than Lower Cretaceous." This single fossiliferous bed does not prove, however, that lower in the group there may not be beds older than Upper Jurassic, or that above it there may not be beds younger than Lower Cretaceous. The next younger formation in the region the age of which is known is the Cantwell formation, of Eocene age. The lowest Cantwell beds probably lie unconformably above the group in which the Upper Jurassic or Lower Cretaceous fossils were found and are separated from the fossiliferous bed by 2,000 feet or more of sediments. It is quite possible that some of these beds are of Upper Cretaceous age. Farther southwest, in the Yentna, Kichatna, and Skwentna Basins, on the southeast flank of the Alaska Range, and in a position with respect to the axis of the range similar to that occupied by the Jurassic or Cretaceous beds here under consideration, shale, argillite, and graywacke carrying Upper Cretaceous fossils occur, and further studies in the region here under discussion are likely to prove that Upper Cretaceous rocks are present in this section also.

In the basins of the Savage and Sanctuary Rivers the shales here correlated with the Jurassic or Cretaceous rocks are without question unconformably below the Cantwell formation. If the correlation of these shales with those on the West Fork of the Chulitna River that carry Upper Jurassic or Lower Cretaceous fossils is correct, then the unconformable relation of the Jurassic or Cretaceous rocks of the entire region with the Cantwell formation is proved, and deformation of the Jurassic or Cretaceous rocks, with subsequent deep erosion of these shales, took place during an interval which occurred in Cretaceous or lower Eocene time. The exact time of this erosion period can not be ascertained until fossil collections are obtained that determine the upper time limit of the Jurassic or Cretaceous shales and the lower time limit of the Cantwell formation.

CANTWELL FORMATION

Character and distribution.—The Cantwell formation has a wide distribution on both flanks of the Alaska Range. It has been recognized as far westward as the headward basin of the Tonzona River, in the Kuskokwim drainage area, and occurs east of that point in small areas as far as Muldrow Glacier. East of that glacier it increases greatly in area and is perhaps the most widespread single formation in the high mountains of the range eastward as far as the headwaters of the Susitna River. On the south slope of the range, in the area here under consideration, the Cantwell formation extends from the west fork of Windy Creek westward in a gradually widening belt as far as West Fork Glacier, beyond which its extension lies in an unexplored region of rugged mountains and great glaciers.

The Cantwell formation was recognized by the earliest geologic expeditions into this part of Alaska and has been described in some detail by numerous authors.[24] Except for some significant facts concerning its distribution and structural relations, the earlier descriptions are adequate and will be summarized briefly here. The Cantwell formation was first described and named by Eldridge, who found beds of conglomerate and coarser sandstone along the Nenana River between Windy Creek and the Yanert Fork. Eldridge had no information and made no suggestion as to the age of the formation. Four years later, in 1902, Brooks saw and mapped these rocks from Muldrow Glacier eastward into the basin of the Yanert Fork. Brooks recognized the fact that this formation included, in addition to Eldridge's conglomerate and sandstone, a thick series of associated sandstone and shale, and he found plant remains of Eocene age in shale closely associated with the Cantwell. Brooks had, however, reached the conclusion from other lines of reasoning that the Cantwell formation was of pre-Mesozoic age, and he therefore concluded that the fossil plants he had collected had been faulted into the position in which he found them, and he reached the tentative conclusion that the Cantwell was of Pennsylvanian age. In 1910 the writer observed firmly cemented sandstone, shale, and conglomerate on the upper Wood River, east of the area here described. He recognized their probable Tertiary age but correlated them with the Tertiary coal-bearing formation, for the Cantwell was then still considered Carboniferous. In 1913 Moffit extended the known area of Cantwell rocks eastward into the upper Nenana Basin, demonstrated their

[24] Eldridge, G. H., A reconnaissance of the Susitna basin and adjacent territory, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 16, 1900. Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, pp. 78–83, 1911. Moffit, F. H., The Broad Pass region, Alaska: U. S. Geol. Survey Bull. 608, pp. 40–49, 1915. Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, pp. 28, 1912; The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 38–44, 1919.

Tertiary age, and showed that the beds in the upper Wood River basin, which the writer had earlier thought were a part of the Tertiary coal-bearing formation, really belonged in the Cantwell formation. In 1916, 1917, and 1919 the writer extended the known areas of Cantwell rocks into the headwater basins of the Savage, Teklanika, and Toklat Rivers, on the north slope of the range, and into the upper basin of the West Fork of the Chulitna River, on the south slope. In 1930 he showed that Cantwell rocks occur continuously on the south slope of the range, bordered on the north by a great fault, from Windy Creek westward to Anderson Pass, and extending thence an unknown distance into unexplored areas.

The borders of the Cantwell areas, as shown on Plate 4, are determined in a variety of ways. In places the shapes of the margins are due to the accidents of erosion, glaciers and streams having cut through the Cantwell to expose older, underlying rocks. At other places the Cantwell is in contact with post-Cantwell intrusive rocks. Faulting has brought the Cantwell beds against a great variety of older materials. Over considerable areas lava flows of Cantwell or younger age have covered the sediments, and elsewhere the younger Tertiary coal-bearing formation and glacial and stream deposits conceal the Cantwell beds. The Cantwell formation consists almost exclusively of clastic sediments, ranging from coarse, massive conglomerate containing pebbles as large as 6 inches in diameter through finer conglomerate to coarse, gritty sandstone, and this into shale. In many places the lowest part of the Cantwell is a coarse, massive conglomerate 200 feet or more thick, including well-rounded cobbles and pebbles that represent most of the older formations of the region. This basal conglomerate can not be everywhere recognized, however, and in places, particularly on the West Fork of the Chulitna River, it has not been possible to be certain of the plane of contact between the Cantwell and the underlying Jurassic or Cretaceous beds. Above the basal beds there is a succession of interbedded sandstone, grit, shale, and conglomerate, in which the individual beds range in thickness from a few inches to many hundreds of feet. The succession is probably not the same at any two places, for a single bed may vary along the strike, being fine grained in one place and coarse grained not far away. Furthermore, in the fine exposures of little-disturbed beds that occur along the head of the West Fork of the Chulitna River it can be observed that many of the coarser beds are distinctly lenticular, a conglomerate several hundred feet thick thinning out and disappearing within a distance of a few miles, perhaps to be replaced by another conglomerate a little higher in the section. In a general way, however, the proportion of conglomerate decreases and that of shale increases upward in the section, though conglomerate recurs in the formation from top to bottom. In color the Cantwell sediments range from light gray sandstone and conglomerate to dark, nearly black conglomerate, sandstone, and shale. They include some buff and reddish beds, but the colors are prevailingly somber. These dark beds contrast sharply with the brilliant colors of the associated lavas and add greatly to the striking scenery of the upper Teklanika, the East Fork of the Toklat and Toklat Valleys, and Polychrome Pass.

The conglomerate, sandstone, and shale of this formation are well indurated throughout and weather into bold, rugged forms. The peaks of many high mountains are composed of these materials, and the coarser beds, particularly the hard conglomerate, produce many fantastic and picturesque forms. The shale and argillite are generally less resistant to erosion than the sandstone and conglomerate, and where the formation is largely composed of the finer beds the relief is less bold and the slopes are smoother than where coarser materials prevail. In many exposures the hard, coarse-grained beds stand out as parallel plates of high relief, the shale having weathered into deep troughs between them.

Moffit showed that east of the Nenana River the Cantwell sediments exhibit a progressive change from little-altered sediments, through materials that show increasingly the effects of metamorphism, to highly metamorphic rocks that include mashed conglomerate, black slate, and mica schist. He traced the rocks through these different stages and entertained no doubt that the slate and mica schist of one locality were contemporaneous with the little-altered sediments seen elsewhere. The writer during the summer of 1930 carried the geologic mapping westward from the area studied by Moffit and found that between Windy Creek and Anderson Pass, an east-west distance of at least 50 miles, the Cantwell beds are broken by a great fault that drops them down against the Devonian and older rocks that border them on the north. Along this fault, or rather fault zone—for the zone of movement is in places several hundred feet wide—both the Cantwell beds and the beds against which they have been faulted are tremendously mashed, sheared, and stretched. The shales are locally mashed to a mass of gouge and small rock particles, and the conglomerates are in places sheared, stretched, and schistose. Here and there the conglomerate is so far altered that its original character is difficult to determine. This great fault was mapped by Moffit for a few miles on each side of the Nenana River, though he had no knowledge of its great length and displacement to the southwest. Between the Nenana River and Anderson Pass, where the fault lies at right angles to most of the drainage lines, its course is everywhere marked by topographic depressions and low passes, the result of the easy erosion of the mashed and weakened rocks of the fault zone. East of the Nenana River there is also a striking succession of valleys and low passes along the projected line of this fault, and along this line the Cantwell conglomerates are sheared, mashed, stretched, and schistose. It therefore seems highly probable that the fault is there continuous, at least as far eastward as the glacier at the head of the Nenana River. West of Anderson Pass the northeastward-trending portion of Muldrow Glacier and the upper portions of Hanna Glacier also occupy valleys that lie along the line of the fault if that fault is projected to the southwest, and those depressions, having an anomalous direction parallel with the trend of the range, strongly suggest that the great fault is continuous southwest of Anderson Pass for another 34 miles, although it has not actually been traced so far. If these lines of depressions and passes to the east and west of the area here described actually represent the response of erosion to the weakened rocks of the fault zone, we have here a great fault that for 120 miles is a major structural feature of the Alaska Range.

On the north slope of the range the Cantwell beds are locally much deformed, but nowhere were they observed to have been so greatly altered as to approach slate and schist in appearance. Blocks of conglomerate seen on the moraines of Muldrow Glacier are apparently divided from the Cantwell formation and indicate that it extends westward from Anderson Pass toward Mount McKinley. The Cantwell formation throughout carries carbonaceous material, commonly in thin, scattered lenses, which represent vegetable material now turned to lignite. Although this carbonaceous matter can be recognized from its shape as having originally been leaves, twigs, or sticks, its structure and surface markings are generally too poorly preserved to permit identification of the plants by the paleobotanist. At a few places thin seams of sheared lignite less than an inch thick were seen, and at one place on the west side of the Nenana River, near Yanert, an attempt was made to mine a coal bed that was thought to lie in the Cantwell formation, though possibly it may be an unusually well indurated portion of the coal-bearing Tertiary formation. At only a few places have fossil leaves sufficiently well preserved for identification been found.

Associated with the sedimentary Cantwell beds there are in places large quantities of volcanic rocks, which occur both as intrusive dikes and sills and as lava flows interbedded with the sediments. The lava flows are especially abundant in the Teklanika and Toklat Basins, but throughout the area occupied by the Cantwell beds there are dikes, sills, and stocks of intrusive material, though they differ greatly in abundance from place to place. Several masses of coarsely crystalline granitic rocks of considerable area cut the Cantwell beds, and the coarse grain of these materials indicate that they cooled beneath a fairly heavy cover of material and that since their intrusion erosion has removed a considerable thickness of beds to expose the fairly deep seated intrusive rocks. The lava flows, interbedded with the Cantwell sediments, and the associated intrusive dikes and sills are particularly abundant on the north side of the range in the Sanctuary, Teklanika, and Toklat Basins, along the route of the park road that leads from the railroad to the vicinity of Muldrow Glacier. They include rocks of considerable range in texture and composition, among them rhyolite porphyry, rhyolite flows and tuffs, andesite, dacite, diabase, basalt, and amygdular greenstone, as well as coarser-grained intrusive rocks including granite, monzonite, diorite, and gabbro. The flow rocks interbedded with the Cantwell sediments are especially vivid in coloring and include hues ranging from white to cream and light tints of pink, red, green, and purple to darker shades of brown, red, and green. Near-by intrusive rocks include dark-green, purple, and black diabase and greenstone. Wherever these rocks are well exposed in the high, rugged mountains, their contrasting colors produce vivid and beautiful scenery.

Though the Cantwell beds contain the remains of land plants, they have failed to yield any trace of marine fossils. It is believed that the beds were laid down as continental land deposits, largely by streams but perhaps locally in small, shallow lakes. They were therefore accumulations of mud, sand, and gravel in stream valleys or on a piedmont plain near some land mass from which the materials were derived. The coarseness of the material shows that this land mass stood rather high, for the streams must have had fairly steep gradients to carry the coarse gravel and sand that make up so large a part of the formation. Furthermore, an enormous quanitity of material was necessary to furnish the existing Cantwell sediments. They are known for an east-west distance of at least 170 miles, and the belt in which they occur has a present width from north to south of 25 miles. It is not known that Cantwell beds were ever continuous throughout this area, but recent investigations suggest strongly that they once extended entirely across the site of the present Alaska Range in the eastern part of Mount McKinley Park, and it is certain that their original area was much larger than their present area. To supply the materials for this formation required the erosion of a land mass certainly as large and probably much larger in volume than that of the existing Cantwell sediments derived from it. The volume of these sediments was undoubtedly many hundreds of cubic miles, yet neither the location of this land mass nor the age of the rock formations of which it was composed has been definitely ascertained.

Structure and thickness.—Within the area here described the structure of the Cantwell formation is complex, though less so than that of the rocks upon which it lies unconformably. On the south flank of the mountains, south of the great fault, the Cantwell beds have a general monoclinal dip to the north that perhaps averages 15° or 20°, though the structure is by no means so simple as such a general statement indicates. Faults of minor displacement are common within the formation. The beds have also been affected by large, open folds, and upon these larger folds there has been locally superposed close folding, crushing, and crumpling. Near the line of the great fault the beds are intensely sheared and mashed, the conglomerate is stretched and schistose, and the shale is mashed to fragments or reduced to a formless mass of clayey material. North of the range the beds exhibit a wide range in the degree of deformation they have undergone. In general terms the Cantwell beds there can be said to lie in a broad synclinal trough, the south border of the trough upturned against the Paleozoic rocks along the crest of the range, and the north limb bordered by the Paleozoic and pre-Paleozoic rocks of the outer range of foothills. Within this synclinal trough the Cantwell beds rest unconformably upon all the older formations, including the pre-Cambrian Birch Creek schist, Paleozoic beds of different kinds, and Mesozoic lavas and sediments. Here also the synclinal structure of the Cantwell is general only, for there are within that basin numerous folds, both anticlinal and synclinal, faults of considerable displacement, and local areas of intense folding and crushing, whereas elsewhere monclinal dips prevail over considerable areas. In the main, however, these structural features lie parallel with the axis of the Alaska Range and were doubtless developed during the growth of that range in post-Eocene Tertiary time. In detail, compressive stresses within the region are indicated by a great variety of structure. One common response to compression has been the development of bedding faults by the sliding of adjacent beds upon one another. Such faults are inconspicuous, and the amount of displacement along them is generally difficult to determine. Here and there, however, a locality may be found where a dike, intruded before the compression took place, has been offset by bedding faults, and it is there evident that although the relative movement between adjoining beds may be small, the total displacement accounted for by many such bedding faults may be large. Other results of compression are close, overturned folds, close crumpling, intimate distortion, and mashing, all of which were observed in places.

The folding, faulting, and deformation to which the Cantwell formation has been subjected took place during the mountain-building processes that acted along the site of the present Alaska Range but that preceded the last upward movement of the mountains. Certainly no mountains existed in early Tertiary time in the area now occupied by the Cantwell formation, for its materials were of necessity deposited in low-lying areas. A part of the deformation preceded the deposition of the coal-bearing Tertiary beds, for the Cantwell was indurated, tilted, and eroded before the coal-bearing materials were laid down. Whether or not the great fault along the south flank of the range preceded or followed the deposition of the coal-bearing part of the Tertiary is not certainly known, for these beds have not been observed immediately adjacent to the fault. Nevertheless, it may be reasoned that the fault is older than the last uplift, which gave the range its present height. In the area west of the Nenana River the south side of the fault certainly had a maximum displacement of 10,000 feet, and possibly much more than that, and the south side was the downthrown side. Yet from Anderson Pass westward the highest portions of the Alaska Range are on the downthrown side of the fault. These facts suggest that the topographic relief of the surface due to this fault was reduced by the erosion that followed the deposition of the Cantwell and preceded the deposition of the Tertiary coal-bearing beds, and that the present relief of the range is the result of regional uplift and folding after the coal-bearing formation was laid down. A considerable part of the general uplift of the present range, however, is known to have been later than the coal-bearing formation, and that uplift was accompanied by compression and by folding that involved both the Cantwell and the younger coal-bearing formation.

In no one section is the original, uneroded thickness of the entire Cantwell formation exposed, and it is therefore not yet possible to state what that maximum thickness is. On the south side of the range the northward-dipping Cantwell beds are cut off by the great fault, and their thickness where exposed has been diminished by erosion. Yet in the ridge north of the head of the West Fork of the Chulitna River, where the beds are not folded and only moderately tilted, an incomplete section shows 4,000 feet of Cantwell beds. On the north side of the range at many places the remaining portion of the formation is 2,000 to 3,000 feet thick. Moffit [25] calculated a thickness of approximately 2,700 feet in a single mountain in the Broad Pass region near the mouth of Jack Creek and believed that that measurement represented only a part of the section. From the evidence now at hand it appears that the maximum observed thickness of the Cantwell formation is at least 4,000 feet and that there the section was incomplete. The original maximum thickness of the formation may be much more than that amount.

[25] Moffit, F. H., op. cit. (Bull. 608), p. 47.

Age and correlation.—In Eldridge's original description of the Cantwell formation he expressed no opinion as to its age. The name he took from what was then called the Cantwell River but is now called the Nenana, the valley of which is cut in this formation from the mouth of the Jack River to the mouth of Riley Creek. The first attempt to assign these beds to a definite stratigraphic position was made by Brooks [26] as a result of his field work in 1902, during which he traced the formation from a point near Muldrow Glacier eastward to the Nenana River and for 25 miles up the Yanert Fork. He found the Cantwell formation lying unconformably upon beds of probable Middle Devonian age and expressed the opinion that it was pre-Eocene, although recognizing its structural and lithologic resemblance to Eocene beds in other parts of Alaska. Brooks even found Eocene plant remains in shale resembling the Cantwell shale, but the beds were associated with faults, and from other considerations he concluded that the Cantwell formation was pre-Mesozoic and that if so it would most likely be Carboniferous. Moffit, however, as a result of his work in the Broad Pass region in 1913, unqualifiedly assigned the Cantwell to the early Tertiary (Eocene). He collected fossil plants from several localities on the West Fork of Wells Creek, and the following forms in his collections were identified by F. H. Knowlton and Arthur Hollick:

Locality 6565. Ten miles east of mouth of Jack River:

Taxodium tinajorum Heer.
Taxodium dubium (Sternberg) Heer?
Sequoia langsdorfii (Brongniart) Heer?
Populus arctica Heer?
Daphnogene kanii Heer?

Locality 6567. Ten miles east of mouth of Jack River (near locality 6565):

Aspidium heerii Ettingshausen?
Taxodium dubium (Sternberg) Heer?
Ginkgo adiantoides (Unger) Heer?

The leaves collected by Brooks from the Toklat Basin included forms like three of the species in lot 6565.

Another fragmentary collection, made by the writer on Big Creek, a tributary of the Teklanika River, at a point about 4 miles above the mouth of Big Creek, and identified by F. H. Knowlton, contained isolated leaves of *Pinus?* sp. and what appear to be branchlets of *Sequoia langsdorfii.* All these collections have been assigned to the Eocene.

In this region the youngest identified rocks beneath the Cantwell are Upper Jurassic or Cretaceous shales. Farther southwest, along the southeastern slope of the range, slate and graywacke of probable Upper Cretaceous age have been identified, and these beds, as judged

[26] Brooks, A. H., op. cit. (Prof. Paper 70), p. 81.

by their character and metamorphism, are older than the Cantwell. Both the stratigraphic and the paleontologic evidence therefore point to an age for the Cantwell younger than part of the Upper Cretaceous.

In determining its age from the evidence of overlying formations some difficulties present themselves. The next younger formation, the Tertiary coal-bearing formation, is much less indurated, is less folded, is freer from associated intrusive rocks and lava flows, and appears to lie with angular unconformity above the Cantwell, yet fossil plants from both the Cantwell and the coal-bearing formation are remarkably similar, and all have been identified as of Eocene age. Nevertheless, every geologist who has studied the two formations in the field in this region agrees that the field evidence is convincing that the coal-bearing beds are much younger than the Cantwell. Both the paleobotanic and the stratigraphic evidence, however, show the Cantwell formation to be of Eocene or possibly of late Upper Cretaceous age.

TERTIARY COAL-BEARING FORMATION

Character and distribution.—Coal-bearing sediments of Eocene age occur at many places along both flanks of the Alaska Range. This formation has been recognized at intervals on the north slope of the mountain front from the Kuskokwim Basin eastward to the international boundary, a linear distance of 400 miles, and on the southeast and south slope from lower Cook Inlet to the head of the Susitna Basin and thence eastward into the Copper River Basin. In spite of this wide distribution, however, the occurrences are sporadic, and it is unlikely that the beds, even as deposited, were continuous between these areas. This patchy distribution is the direct result of the conditions under which this group of sediments was laid down. The Tertiary coal-bearing formation is composed of little-consolidated gravel, sand, shale, and lignitic or subbituminous coal, all of which were deposited by streams or in lowland areas in which there were no large bodies of standing water. There is no evidence that any of this formation was laid down in marine waters, and the only fossils are plant remains that indicate deposition under subaerial conditions or in small shallow lakes. It is believed that these beds were originally confined to relatively narrow, open stream valleys or to somewhat broader lowland areas into which streams flowed from highland areas of moderate relief located in about the position of the present mountains of this part of Alaska. In certain favorably situated lowlands, notably the one now occupied by Cook Inlet and the Susitna River and its larger tributaries and another on the interior slope of the present Alaska Range, extending from the Sanctuary River eastward into the upper basin of the Totatlanika River, there are fairly broad areas that received these materials, and possibly they occur in another broad basin, that of the Tanana lowland, though there later deposits of alluvial material conceal any Tertiary beds that may be present. Elsewhere the areas occupied by these beds are small, and they are probably never connected with one another.

The Tertiary coal-bearing formation in Cook Inlet and the Susitna and Tanana Basins has already been described by numerous authors,[27] several of whom have visited the region here under consideration. Within the eastern part of the Mount McKinley region the deposits of the Tertiary coal-bearing formation are scattered and of small area, and none are at present of commercial value. The general characteristics of the formation will therefore be only briefly summarized here.

An adequate description of the formation as a whole in this region must refer to the Nenana coal field, which lies outside of the area here considered but in which the section is most completely developed and best known. This field contains the largest reserves of minable coal of this age, some of which is now being mined on a commercial scale. On Healy Creek a completely exposed section shows a thickness of 1,900 feet of coal-bearing beds, consisting of gravel, shale, sand, and lignite, of which 220 feet is lignite in 23 separate beds. The stratigraphic relations at this locality are typical of the formation in many other places. The basal beds consist of about 100 feet of smoothly rounded pebbles of chert and white quartz in a matrix of white sand and kaolinic material, lying unconformably upon the Birch Creek schist. The conspicuous white color is characteristic over wide areas and is of great value in identifying the base of the formation. Above the white basal gravel are alternating beds of shale, clay, sand, and lignite and some fine gravel. The lignite beds are thickest and most numerous in the lower half of the section, where there are seven beds that aggregate 174 feet of coal. In the upper half of the section the coal occurs in thinner beds, and fine gravel is more abundant. The formation is succeeded above, in apparent conformity, by a thick deposit of gravel. This Healy Creek section contains more known coal than any other section that has been examined, though at other places much of the formation is not exposed, and the amount of coal present below the lowest exposures is not known.

[27] Brooks, A. H., op. cit., pp. 94–103. Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, pp. 26–29, 1912; The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 44–51, 1919. Martin, G. C., The Nenana coal field, Alaska: U. S. Geol. Survey Bull. 664, 54 pp., 1919.

Within the limits of the area shown on Plate 4, no such extensive areas or thick sections of the coal-bearing formation as those on Healy and Hoseanna Creeks occur. The principal occurrences are in the basins of the Savage, Sanctuary, and Teklanika Rivers, near the north boundary of the park; in the basin of the East Fork of the Toklat River near Polychrome Pass and in Highway and Thorofare Passes; in the headward basin of Moose Creek; on the Nenana River near Yanert station; and in the lowland near Broad Pass. All these occurrences lie in passes or in stream valleys, and none are in high mountains or areas of great relief. This relationship of the coal-bearing formation to lowlands and to low passes between more rugged areas is not accidental but is a direct result of two causes—(1) the beds as originally laid down were confined to lowland areas, and (2) as the deposits of the coal formation consist largely of unconsolidated or easily eroded materials, they were more readily removed by streams and glaciers during the general erosion of the region than were the associated more resistant formations, and the position of valleys or low passes where these beds occur was determined by their easy erosion. The economic importance of this formation is much greater than its area would indicate, for almost everywhere that the formation occurs it contains coal beds and so provides a source of fuel for local use at many places where other fuel would be difficult and expensive to obtain. It is unlikely, however, that any of the coal-bearing beds in this region will be developed on a large scale, or at least not until the abundant and more accessible coals of the Matanuska Valley and of the Healy-Hoseanna Creek field have been exhausted.

Probably the area within this region that contains the most coal is that in the basins of the Savage, Sanctuary, and Teklanika Rivers, near the north boundary of the park. This field includes an area of several square miles in which the presence of coal beds is indicated by the outcrops along the streams, though later gravel deposits cover most of the probable coal-bearing area. The base of the formation, consisting of white quartz gravel and sand, lies unconformably upon the Birch Creek schist to the south, and the beds dip northward beneath the terrace gravel. Coal beds 2 to 14 feet thick were seen, and there is no doubt that this field contains a large tonnage of coal.

Along the route leading from McKinley Park station to Muldrow Glacier the coal formation, with coal at least sufficient for local use, occurs near the west end of Sable Pass, in Polychrome, Highway, and Thorofare Passes, and on upper Moose Creek. At none of these localities has enough work been done to determine the amount of coal present, but small amounts have been mined for local use.

Similarly, throughout the Broad Pass depression many localities have been reported at which the coal-bearing formation, containing coal beds, crops out. Most of these occurrences were not visited, but one, on Costello Creek about 6 miles above its mouth, showed an exposure of about 60 feet of the coal-bearing formation. This exposure, apparently near the base of the formation at this place shows beds that dip about 8° E. in which there are three beds that contain coal. The lowest, which contains 6 feet of coal and bone, is overlain by 18 feet of clay shale. This is followed, in order, by 9 feet of coal, 2 feet of clay, and 8 feet of coal. An analysis by A. L. Glover (Inc.) of a sample of this coal from the 9-foot bed, which was taken about 10 feet from the surface, is as follows:

Analysis of coal from Costello Creek, Broad Pass region, Alaska

Moisture (combined)	per cent	7.00
Volatile matter	do	46.60
Carbon (fixed)	do	40.90
Ash	do	5.50
Sulphur	do	.41
British thermal units		11,190

Structure and thickness.—As the coal-bearing formation within this region now occurs only as small, scattered patches, and as the structure within each of those small patches has been determined by the conditions of deposition and of subsequent deformation, the general facts that affected those processes are here briefly summarized. The sediments that make up the formation were deposited by streams in low, basinlike areas at a time when the present site of the Alaska Range was yet a region of low relief, a fact indicated by the character of the sediments themselves, for they are dominantly fine shale, clay, and sand. The deposition of the organic materials that make up the lignite beds must have taken a long period of time, during which little detrital material was laid down, for the coal beds were formed by the slow growth and accumulation of vegetation, and while they were being built little stream-borne débris was brought in. The detrital materials are much finer than the sediments now being handled by the streams in the same areas and point to low gradients and comparatively sluggish streams during the growth of the formation. Apparently the drainage lines on the north side of the range then followed a general easterly direction, in contrast to the present northward flowing drainage, whereas on the southeast side there was apparently a lowland in about the same position as Broad Pass and its extensions to the east and southwest.

Much of the deformation and uplift of the present Alaska Range has been accomplished since the coal-bearing formation was laid down, and the mountain-building processes of folding and faulting have affected these deposits as well as the older rocks of the region. The compression and warping of the crust during the growth of the range was comparatively slight in the foothills and lower flanks of the mountains, where the coal-bearing sediments are most abundant, but in the higher mountains it was severe, and the small areas of this formation that occur there are more highly deformed that those on the borders of the range. Thus the areas in the upper Toklat Basin and on the head of Moose Creek are synclinal, with both limbs lying upon older rocks and dipping steeply toward the axis of the basin. On the other hand, the Teklanika-Savage River area and the coal beds in the Broad Pass depression lie in broad basins near the margins of the region affected by the uplift and folding of the Alaska Range. They were for that reason only moderately compressed, and the average dip of the coal beds is gentle.

Little information concerning the maximum thickness of this formation has been obtained from the McKinley Park area, for the exposures there are small and discontinuous. The nearest locality at which anything like a complete section is exposed is on lower Healy Creek, a short distance north of this region, where the formation is about 1,900 feet thick. In the scattered areas shown on Plate 4 the formation probably does not reach so great a thickness. The beds were laid down in shallow basins in which deposition took place first in the lowest parts; later, as the beds increased in thickness, their area also increased. Thus the formation continued to expand in area as it thickened, the higher beds overlapping onto the older rocks around the margins of the basins. Only over the deepest parts of the basins was the full thickness of beds developed, and measurements taken elsewhere will show an incomplete section, even though the formation is exposed from the underlying older rocks to the cover of Nenana gravel.

Age and correlation.—The age of the coal-bearing formation in this part of Alaska has been determined from the fossil plants found in it, from its stratigraphic relations to overlying and underlying formations, and by correlation with other beds of similar lithology and stratigraphy elsewhere in the Territory. Although plant remains in the form of lignite and subbituminous coal and carbonaceous imprints of leaves and twigs are common, they have in general been so completely altered that the plant forms can no longer be identified. Furthermore, the inclosing sediments are little consolidated, and the plant imprints will not stand the handling incident to their collection and transportation for identification. Within the region here considered no identifiable fossils have been collected, but in near-by areas, particularly in the Nenana coal field, where there can be no doubt about the identity of the beds with those occurring in McKinley Park, certain shale beds have been hardened by the burning out of adjacent coal beds, and in these burned shales excellently preserved leaf imprints have been found. These leaves have been referred to the Eocene, and in the lower Cook Inlet region the Eocene coal-bearing formation has been called the Kenai formation. That name has, however, been limited to the occurrences near Cook Inlet. Yet from the fossil evidence and from the pronounced lithologic similarity of the Eocene coal-bearing formation of Cook Inlet to that in this region and elsewhere along the north flank of the Alaska Range, there seems to be no reason to doubt that at least some of the coal beds of this region are the correlative of some parts of the Kenai formation. It has not yet been demonstrated, however, that the entire age range of the coal-bearing series is the same throughout the Territory, and until more evidence on this point is available it has seemed best not to apply the term Kenai formation to beds far from the type locality on Cook Inlet. Nevertheless it is thought to be highly probable that some beds of the same age are present in both the Kenai formation and the coal-bearing formation of this region.

The fossil plants from the coal-bearing formation have been assigned to the Eocene. So also have the plants collected from the Cantwell formation. Yet all geologists who have worked in this part of Alaska are agreed that the field evidence shows inescapably that the coal-bearing formation is considerably younger than the Cantwell and that the two formations differ greatly in character, in appearance, and in their evidences of age. To be sure, both are composed of clastic sediments deposited under subaerial conditions, mainly by streams, and both are lacking in animals remains that might be used as criteria for determining their age. Yet the two formations have pronounced differences, which may be briefly summarized as follows: The Cantwell beds are generally dark colored, and are everywhere well indurated and comprise hard rocks, including shale, sandstone, and hard conglomerate, whereas the beds of the coal-bearing formation are conspicuously light colored, the prevailing hues being white, cream, and buff, and consist of only moderately or little indurated rocks. The Cantwell formation, although presenting extensive, clean exposures, is almost completely lacking in coal beds, whereas the coal-bearing beds, even in the midst of areas of highly deformed Cantwell sediments, are less steeply folded, preserve their light colors and incoherent character, and in nearly every extensive exposure show the presence of coal beds. The Cantwell sediments are in many places interbedded with large quantities of extrusive igneous rocks and are cut by numerous dikes and sills. The coal-bearing formation is generally free from igneous rocks and at only a few localities is known to contain igneous material.

As the coal-bearing beds and the Cantwell beds have not yet been found in direct contact, the relative age of the formations can not now be proved by the superposition of one above the other, but the field evidence leaves little doubt that the coal-bearing formation is the younger. Its general lack of induration and its lesser deformation indicate this, as does the stratigraphic relation of the two formations in Toklat and Stony Basins. The coal-bearing beds in Highway Pass form a simple syncline, whereas the Cantwell beds in Divide Mountain, just to the east, are highly deformed. The coal-bearing beds were there deposited in a valley that had previously been eroded into a group of hard rocks of which the Cantwell formation is one. A similar situation exists farther west, in the pass between Stony Creek and the southeast head of Moose Creek. The Cantwell in the area just north of the pass, where it is separated from the coal-bearing beds only by a narrow belt of igneous material, is standing on edge and is composed of thoroughly indurated black materials. The coal-bearing beds, apparently here also deposited in a valley eroded into the lavas and Cantwell sediments, are unconsolidated, of light color, and much less deformed than the Cantwell. They contain pebbles of a conglomerate that is identical in appearance with much of the Cantwell conglomerate. If the conglomerate pebbles were derived from the Cantwell the younger age of the coal-bearing beds at this place is proved, for the Cantwell conglomerate, to have yielded the pebbles, must first have been indurated to a hard rock and then subjected to erosion.

The facts above cited have convinced the writer that the coal-bearing formation is younger than the Cantwell. The field evidence indicates that after the Cantwell was laid down it was indurated, cut by intrusive rocks, deformed, and eroded before the deposition of the coal-bearing formation. Yet between the fossil plant collections made from the two formations the paleobotanists make no distinction. The conclusion is inevitable either that the field evidence has been misinterpreted; that a single assemblage of plants persisted in this area for a long time; or that sufficiently detailed studies of the plant collections have not been made to distinguish between floras that were separated by a considerable time interval. The writer's conclusion is that if both the Cantwell and the coal-bearing formation are Eocene, then we have in this part of Alaska two Eocene formations that are separated by a considerable interval during which induration, severe regional compression and uplift, and later deep erosion took place.

NENANA GRAVEL

Character and distribution.—The term Nenana gravel was first used by Capps [28] to designate a series of elevated gravel beds that reaches a widespread development on the north flank of the Alaska Range and is well exposed on both sides of the Nenana River near the mouths of Hoseanna, Healy, and Dry Creeks, just north of the area here under consideration. These gravel deposits were first observed by Brooks and Prindle in 1902, were regarded as of glacial origin, and were grouped with the other Pleistocene deposits on the geologic map.[29] In 1906 Prindle [30] again visited this region, and noted that wherever their structural relations could be observed these gravel deposits and the underlying coal-bearing formation were structurally conformable, whether in horizontal or tilted strata. He also made a distinction between gravel deposits of various ages, some of which were younger than the Nenana gravel. In 1910 and again in 1916 the writer [31] studied the gravel deposits on the north side of the Alaska Range, both east and west of the Nenana River, outlined the areas in which they occur, and arrived at the conclusion that they are of Tertiary age.

The Nenana gravel reaches its greatest development in the foothill belt north of the main mass of the Alaska Range between the Toklat River and the Delta River, where it covers extensive areas between the alluvial Tanana lowland and the rugged mountains to the south. Within the area here described it occurs in smaller patches, chiefly in the basins of the Savage, Sanctuary, Teklanika, and East Fork of Toklat Rivers and just west of Muldrow Glacier. On the geologic map it has been shown only where its character is evident and where it is not covered by later materials.

The Nenana gravel forms a thick series of unconsolidated or only loosely cemented materials consisting mainly of rather coarse, well-rounded gravel, with only subordinate amounts of interbedded layers of sand. Most of the pebbles range in diameter from 1 inch to 3 inches, though in places cobbles and small boulders a foot or more in diameter occur. In one exposure that was noted about 5 per cent of the section was composed of thin sand beds. The pebbles include a great variety of rocks, among the commonest of which are quartz, quartzite, schist, conglomerate, and igneous rocks of a wide range of composition. It is unlikely that these coarse materials were trans-

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[28] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, pp. 30–34, 1912.

[29] Brooks, A. H., op. cit., pl. 9.

[30] Prindle, L. M., The Bonnifield and Kantishna regions: U. S. Geol. Survey Bull. 314, p. 222, 1907.

[31] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, 64 pp., 1912; The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, 118 pp., 1919.

ported any great distance from their bedrock source to the places in which they are now found, and as would be expected, the character and relative proportions of different kinds of pebbles in the gravel differ from place to place, depending on the kind of rocks that made up the highlands from which the gravel was derived. The deposition of the Nenana gravel probably began soon after the initiation of the last pronounced uplift of the Alaska Range that followed the formation of the coal-bearing Tertiary rocks, and the gravel is most likely the product of erosion by vigorous, rejuvenated streams that drained from that recently elevated highland. In some places the gravel is sufficiently cemented to stand as steep cliffs, but on weathering the sandy matrix crumbles and frees the pebbles. A characteristic feature of the Nenana gravel is its yellow or buff color. This color is due to the oxidation of iron-bearing minerals in the sandy matrix and in the pebbles and indicates that the deposit is older than the blue and gray unoxidized gravel of the present streams and than the morainal materials left during the last great ice advance. At many places the Nenana gravel has been eroded by the present streams, and within these younger valleys the streams have formed terraces and flats of gravel that was in part at least derived from the Nenana gravel. In these places the younger deposits may either lie with apparent conformity upon the older gravel where those deposits were nearly flat lying, or be obviously unconformable upon the Nenana gravel where it is tilted. Where there is no obvious angular unconformity between the gravel deposits it is easy to mistake younger terrace gravel for the Nenana gravel, particularly if the younger beds are composed mainly of reworked material from the bordering Nenana gravel ridges and in consequence have inherited the yellowish color of the parent formation. Normally the color of the gravel deposit under examination is an important criterion in determining whether it is Nenana gravel or younger, but in some places the physiographic form and relationships must be relied upon. The confusion on these points has led some observers to the conclusion that the Nenana gravel is commonly unconformable upon the coal-bearing formation, whereas according to the writer's observations there is in most places conformity between them. There are, however, localities in which the Nenana gravel lies unconformably upon the coal-bearing beds, as noted below.

In most of the areas in which the Nenana gravel occurs the topographic features formed by its erosion are smoothly rounded, and the gravel is so deeply covered by loose surface material and by vegetation that its structure can not be made out. Only where vigorous streams have cut into the gravel hills and formed bare bluffs can sections showing the character and structure of the beds be found. The present topography is due in part to the structure of the material, but the deposits are so loosely cemented that they break down readily, and in the absence of any hard, resistant beds the gravel yields slopes of smooth outlines and subdued topography.

Structure and thickness.—All the Tertiary formations in this region, including the Cantwell formation, the coal-bearing formation, and the Nenana gravel, were deposited by streams in low-land areas under subaerial conditions. There is no evidence that this region has been generally submerged since the end of Mesozoic time. The Nenana gravel is stream deposited, as is indicated by the character and composition of its material and by the distribution of the formation; and its coarseness, in contrast to the finer sediments that make up the coal-bearing formation, points to a rejuvenation of the streams by an uplift of the area from which they flowed. This is believed to be the first of the upward movements that formed the present Alaska Range. This early uplift is thought also to have affected only the axial portion of the range, while the bordering areas now occupied by the Nenana gravel remained lowlands and received the detritus brought down by the invigorated streams. After the deposition of the gravel, locally to a thickness of nearly 2,000 feet, the area affected by the upward growth of the range became extended and involved the areas earlier covered by the gravel deposits. The growth of the range included bodily uplift, faulting, and folding, the folding being parallel to the trend of the range, and some of these folds involved the coal-bearing formation and its cover of Nenana gravel. Farther out on the flanks of the range these beds were only tilted, and in many places they escaped deformation almost completely. During the later stages of uplift and since the elevation of the range to about its present height and area erosion by streams and glaciers has been active, and the loosely coherent gravel has been deeply dissected. From some areas which it formerly covered it has been entirely removed.

In general the Nenana gravel is believed to lie conformably upon the coal-bearing formation in those sections where both are present. Where the coal-bearing beds are absent the gravel lies unconformably upon some older formation. Locally what appears to be normal Nenana gravel is unconformable upon the coal formation, but this can be explained if the gravel so found is considered to represent not the base of the Nenana formation but some higher portion of it, for the coal formation in places was doubtless involved in the mountain-building movements and eroded during early Nenana time and was covered with gravel later in the Nenana epoch. Certainly in many localities there is apparent conformity between the coal-bearing beds and the overlying Nenana gravel, even where both have been folded and tilted together. It may be said that in general the Nenana gravel is deformed equally with the coal-bearing formation where both occur.

Age and correlation.—The Nenana gravel has yielded no fossils, either of plants or other organisms, and its age is still somewhat uncertain. In the lack of fossils any appraisal of its age must be based on its stratigraphic relations to other formations and on its physiographic position, general structure, and resemblance to other formations of less doubtful age. As first mapped by Brooks [32] the gravel was considered to be directly related to the Pleistocene glaciers and was grouped with the Quaternary deposits. Prindle [33] and Capps,[34] both of whom studied the gravel over considerable areas on the north flank of the range, observed that in most places it lies conformably upon the coal-bearing formation, and that in those places the gravel has been deformed in equal degree with the coal-bearing formation, whereas the glacial deposits and associated outwash gravel are little or not at all deformed. Since these writers first published their observations many other localities have been found where both the Nenana gravel and the coal-bearing formation are exposed in the same section, and in nearly every such exposure the two have been folded or tilted together. On the other hand, at one or two places the undeformed gravel lies with angular unconformity upon the upturned and beveled edges of the coal-bearing formation, so that a part, at least, of the gravel is considerably younger than the coal-bearing formation.

There are many localities where reworked Nenana gravel that simulates in color and composition the original material lies as terraces or benches along valleys eroded into the Nenana gravel and in places appears unconformably above the coal formation. Such reworked materials may easily be mistaken for the original Nenana gravel and may thus give a false idea of the prevailing relationship between that formation and the coal-bearing beds. It is therefore necessary to make a sharp discrimination in the field between the older, undisturbed gravel, and the much younger, reworked benches of similar materials.

The apparent anomaly of conformity between these two formations at most places but definite unconformity at a few localities is best explained by reviewing the conditions that existed in the region while the gravel was being laid down. The deposition of the coal-bearing series was terminated by an uplift of the Alaska Range, which caused the steepened streams to discharge coarse material over areas that had before received only silt, sand, and fine gravel. The

[32] Brooks, A. H., op. cit., pp. 108–109.
[33] Prindle, L. M., op. cit., p. 222.
[34] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, pp. 64, 1912.

uplift was probably not everywhere equal, so that in one place coarse gravel may have been laid down conformably upon the coal formation, whereas elsewhere that formation remained uncovered. As the coal formation also became involved in the uplift its beds may here and there have been tilted and eroded and later unconformably covered with gravel. Therefore conformity between the two formations might be the prevailing relation, whereas in exceptional areas unconformity occurred.

The writer believes that the deposition of the Nenana gravel began immediately after the deposition of the coal-bearing formation and that the accumulation of the relatively fine sediments and the organic remains of the coal-bearing formation was terminated by the outpouring of gravel by quickened streams that flowed from the newly uplifted highlands of the Alaska Range. The determination of the time at which the deposition of the gravel ceased is less certain. Brooks regarded the Nenana gravel as Pleistocene, supposing that it was laid down by flood waters during the retreat of the Pleistocene glaciers. It now seems certain, however, that during the last great ice advance the glaciers moved down valleys that had already been deeply eroded into the Nenana gravel. The terminus of the Nenana glacier at its maximum development during the last glacial stage stood at about the mouth of Dry Creek, where a distinct terminal moraine was deposited. No evidence of glaciation of that stage was observed below Dry Creek. As the Nenana gravel had been uplifted and deeply eroded before that ice advance it is certainly older than that stage. Our knowledge of the glacial history of Alaska before the last great ice advance is scanty, but it is definitely known that there have been at least two glacial stages, one much older than the last, and there may have been several. Many large boulders occur on top of the Nenana gravel on both sides of the Nenana River north of the area here considered, and in localities that are beyond the limits reached by the last great glaciers. These boulders are considered to be of glacial origin and to represent an advance of glaciers, earlier than the last, that were thicker and that pushed farther out from the mountains than the glaciers of the last stage of Pleistocene glaciation. All such boulders, however, lie on top of the Nenana gravel, which must have been present before the ice advanced to it, in order to have received glacial boulders upon its surface. The physiographical development of the gravel, which, after its uplift and tilting, was eroded into mature topographic forms, with deep intersecting valleys, indicates a considerable age for the gravel, as does its advanced oxidation. The stratigraphic conformity of the gravel with the coal-bearing formation, where both have been steeply tilted and deformed, also points to a Tertiary age for both formations.

To summarize briefly, the Nenana gravel, as studied over a long belt along the north flank of the Alaska Range, appears to be generally conformable with the coal-bearing formation, though local unconformities are present. Its deformation, advanced oxidation, and mature topographic forms indicate that it is of considerable age. It is certainly much older than the superposed and unoxidized deposits of the last stage of Pleistocene glaciation, which lie in valleys deeply eroded into the gravel. Boulders of glacial origin lie on its surface above and outside the limits reached by the last great glaciers, but those boulders are found only on the surface of the gravel and not interbedded in it.

Any determination of the age of the Nenana gravel can be only tentative. It is younger than the coal-bearing formation and older than any known glacial deposits. The writer believes it to be of Tertiary age and to belong to that part of the Tertiary that immediately followed the deposition of the coal-bearing formation.

IGNEOUS ROCKS

Igneous rocks are found as intrusive masses in or as lava flows associated with all the sedimentary formations in this region, from the pre-Cambrian Birch Creek schist to the Tertiary coal-bearing formation. They have almost as wide a range in age as the sedimentary rocks. Thus the Birch Creek schist contains basic greenstone that apparently represents lava flows extruded on and interbedded with the water-laid sediments of which the formation is largely composed. If the greenstone is actually interbedded with the sediments it is of course of the same age. The undifferentiated Paleozoic rocks in the Toklat and Teklanika Basin, though dominantly of sedimentary origin, contain some metamorphic rocks of igneous origin. The pre-Devonian schists in the Bull River and Cantwell Creek Basins are cut by dikes of various sorts and contain some basaltic materials that are now altered to serpentine in places. The great series of Middle Devonian and associated beds, though in the main quite free from igneous materials, is cut by a great variety of dikes and sills that range from diabase, gabbro, and basalt to dacite, andesite, monzonite, and granite. Nothing is known of the age of any particular intrusive rock in this series except that it is younger than the beds it cuts.

Basaltic greenstone and basic intrusive rocks appear at many places in the region to occupy that part of the section above the Devonian and associated sediments and below the Triassic sediments. Thus in the Chulitna Basin greenstone flows and tuffs are found beneath the Triassic beds, though the outpouring of basic lavas continued well into Triassic time. In the Toklat Basin and near Muldrow Glacier a series of greenstone flows, apparently at least 2,000 feet thick, appears above the Devonian beds and beneath the Cantwell. The beds are prevailingly dark green, brown, or purple, are commonly amygdular, and in some flows show ellipsoidal structure. These characteristics indicate that the greenstone was poured out as lava flows on the surface or perhaps in part beneath water. It appears to be quite free from associated sedimentary material and contains no fossils. Its age can therefore be determined only by its stratigraphic relations and by correlation with similar beds elsewhere. The greenstone flows and tuffs in the Chulitna Basin are in part definitely pre-Triassic and are probably to be correlated with the pre-Cantwell greenstone of the north side of the range. In the Broad Pass region Moffit [35] found similar greenstone that he tentatively classified as Triassic. In other parts of Alaska there are amygdaloidal greenstone flows that are in part Permian and that seem to occupy the interval between the end of the Paleozoic and the beginning of Mesozoic time, though perhaps occurring in part in the late Paleozoic and in part in the early Mesozoic. The greenstone of the Mount McKinley Park region seems to correspond in character and in stratigraphic position with similar rocks elsewhere in the territory that are of late Paleozoic and early Mesozoic age, and no closer age assignment for it can now be made.

The outpouring of basic lavas and the laying down of fragmental volcanic materials took place also in Triassic time, and the Triassic sediments are cut by dikes and sills that include basalt, hornblende basalt porphyry, dacite porphyry, and andesite porphyry. The younger granitic intrusive rocks also cut through Triassic rocks. A similar assemblage of dikes and sills were intruded also into the Jurassic or Cretaceous beds and the Cantwell sediments. The occurrence of rhyolite, andesite, and diabase lavas in the Cantwell has already been mentioned. Among the intrusive rocks that cut the Cantwell are rocks ranging from basaltic greenstone through andesite and dacite porphyry to diorite, monzonite, and granite. Coarse-grained granitic rocks of post-Cantwell age occur in numerous places in the region, and as many of the dike rocks that cut the Cantwell are similar in character to those already listed as present in the older formations, it is often impossible to determine the age of a particular dike more accurately than to say that it is younger than the host rock in which it is now found. Certainly many of these intrusive rocks are as young as the Cantwell. On the other hand, the Tertiary coal-bearing formation is relatively free from intrusive rocks, though

[35] Moffit, F. H., op. cit., pp. 26–28.

in a few localities cut by dikes. The general statement is justified, however, that most of the igneous activity in the region took place before the coal formation was laid down and that the flows in the coal-bearing beds represent the last volcanic outbursts in the region.

The larger masses of granitic rocks in this region have heretofore generally been considered to be of Mesozoic age and have commonly been assigned to the Jurassic. More recent studies have developed the fact that many such masses cut rocks as young as Upper Cretaceous. In the Broad Pass region Moffit and Pogue[36] recognized and mapped granitic rocks, including monzonite, diorite, granite, and granite porphyry, that range in age from post-Triassic to post-Eocene (?), and from further studies in the McKinley Park region it is apparent that most of the granitic rocks there are of post-Cantwell age and probably older than the coal-bearing formation. It seems certain, therefore, that there was considerable intrusion of granitic material during Eocene time, and proof is still lacking that in this region granitic intrusive rocks of pre-Tertiary age are so abundant as they were formerly considered to be.

QUATERNARY DEPOSITS AND HISTORY

PREGLACIAL CONDITIONS

The birth of the present Alaska Range took place in early Tertiary time, but its growth was intermittent. After the first upward pulse the quickened streams carried the coarse sediments of the Cantwell formation down from the highlands and spread them over the bordering lowlands. This period of active stream erosion was followed by another period of mountain growth, during which the Cantwell beds were indurated and then warped, folded, faulted, and still later themselves subjected to erosion. Apparently this episode did not result in carrying the Alaska Range up to any great altitude, for it was followed by a long period of quiescence during which the finer coal-bearing sediments and the vegetation that later became coal accumulated. Still another uplift caused the resteepened streams to bring down the Nenana gravel and deposit it over the coal-bearing beds and adjacent lowlands. With continued uplift the mountain area then broadened to the north and south and involved the lowlands that hitherto had not been within the uplifted belt. The foothills north of the main range were elevated by faulting and folding, and the vigorous streams there began to intrench themselves into the easily eroded Nenana gravel, the coal-bearing formation, and the ridges of hard rock that crossed their courses. As the soft materials yielded to stream cutting much more rapidly

[36] Moffit, F. H., The Broad Pass region, Alaska, with a section on igneous rocks by J. E. Pogue: U. S. Geol. Survey Bull. 608, pp. 54–65, 1915.

than the hard rocks, the basins between the rock ridges were widened and deepened while the streams were engaged in their slow task of cutting canyons through the rock ridges. The valleys floored with Tertiary unconsolidated deposits thus attained a mature topography while the canyons in the hard rocks were still young.

In preglacial time the topography of the region differed in other respects from that which we now see. The stream valleys, having been carved out by the normal processes of stream erosion, were V-shaped in cross section and followed somewhat crooked courses around the ends of rocky spurs that projected into the valleys from each side. Rock weathering and disintegration covered much of the surface. The streams were adjusted to their gradients and their loads, and the physiography was that of a moderately mature mountainous region. It is possible that small glaciers existed in the heads of the higher valleys, as they do to-day, but these occupied only a small portion of the region as a whole.

GLACIAL CONDITIONS

With the ending of Tertiary and the beginning of Quaternary time a change of climate occurred that inaugurated the Pleistocene or glacial epoch in the Northern Hemisphere. This climatic change involved an increase in precipitation or a reduction in temperature, or both, so that in the mountains of this region more snow fell each winter than melted during the following summer. This condition continued year after year, the snow banks enlarged and joined, and valley glaciers were formed. In the beginning these glaciers were small and were confined to protected basins in the highest valley heads, but as the process continued they became longer, and ice tongues from many tributary valleys converged and joined along the main drainage lines to form great valley glaciers that pushed out from the crest of the range onto the bordering lowlands. Within the confined valleys of the main range the glaciers grew to a thickness of 2,000 feet or more and filled the valleys so that only the higher peaks and ridges projected above the ice surface. On the north side of the range the ice tongues moved out toward unglaciated lowlands, where they spread out and stagnated.

The effect of these thick streams of ice on the valleys through which they slowly flowed is striking and unmistakable. Each glacier was abundantly shod with blocks and fragments of rock, and by the abrasion of these rock fragments upon its bed and walls and the bodily plucking out of any blocks of rock that could be pulled loose the ice stream gradually removed from its path such obstructions as opposed its advance or restricted its channel. Deeply incised cirques were cut into the high ridges, overlapping spurs and irregularities of the valley troughs were removed, and the ice channels were widened and deepened to form wide troughs that were fairly straight or that followed great, sweeping curves. Within the high mountains the changes brought about by the glaciers were chiefly those of the sculpturing of the land forms by erosion. In the lowlands to the north the erosive powers of the glaciers were weakened, melting checked the advance of the ice, and the rock waste carved from the highlands was dropped as moraines or supplied to the rivers to be distributed as broad deposits of outwash gravel.

Older glaciation.—In the northern United States there is abundant evidence that during Pleistocene time there were several distinct stages of glaciation during which great continental glaciers advanced from the north, each stage succeeded by a period of milder climate during which the ice shrank back and exposed the country previously overridden. Our knowledge of the succession of Pleistocene events in Alaska is still far from complete, but enough facts have now been gathered to warrant the statement that during the Pleistocene there was certainly more than one stage of glaciation in Alaska; that the last great ice advance was contemporaneous with the last advance in the northern part of the United States; and that it is quite possible that the ice advances and retreats in Alaska corresponded rather closely with the waxing and waning of the North American continental glaciers. The last great stage of glaciation in Alaska was without much doubt contemporaneous with the youngest or late Wisconsin continental glaciation,[37] but the earlier stages of Alaskan glaciation have not yet been correlated with those that occurred in the central part of the continent.

In this part of Alaska the last glaciers reached so great a size that they destroyed most of the evidence of earlier glaciations. Only near the margins of the glaciated area are such deposits as superposed tills of markedly different age to be expected. No evidence of successive glacial advances has been obtained from the region here described, but farther north, in the Nenana Valley, large glacial erratic boulders have been found high above and to the north of the outer limit reached by the last glaciers, and these prove that this region also has been the scene of successive glacial stages and that at some pre-Wisconsin stage a glacier pushed northward down the Nenana Valley to the edge of the foothills and at the mouth of Hoseanna Creek stood at a height of at least 2,600 feet above the bottom of the valley. Elsewhere in Alaska additional evidences of earlier glaciations have been found,[38] but many more

[37] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 69–75, 1916.
[38] Capps, S. R., Glaciation in Alaska: U. S. Geol. Survey Prof. Paper 170, pp. 1–8, 1931.

facts than are now at hand will be necessary before an accurate history of the events of the glacial stage in Alaska can be written. Nevertheless, a great deal is known about the extent of the Wisconsin glaciers in the Territory, and that knowledge is being added to year by year, as new areas are given closer study.

Advance of the last great glaciers.—Whatever may have been the succession of Pleistocene events in this region, we know that before the last glacial stage began a long time elapsed during which there were no large glaciers here and during which most of the surface was exposed to normal processes of erosion and weathering. In that interval the streams had modified the glacial forms sculptured from the mountains by earlier glaciers, and great quantities of talus, soil, and products of rock weathering had accumulated. With a renewal of climatic conditions favorable for the accumulation of ice the glaciers once more began to form and grow, stretching down the valleys that drained north and south from the crest of the range and again submerging all but the higher peaks and ridges beneath a mantle of slowly moving ice. This ice, though actually consisting of a multitude of valley glaciers, each confined to its own basin and following in the main a previously established drainage line, became so thick that in many places it surmounted low divides between separate stream basins, and through these passes there was an interchange of ice from one basin to the other, the direction of movement depending on the relative level of the glaciers in the two basins. This lateral flow of ice between adjoining basins resulted in the lowering of the passes by ice erosion and made possible the present easy routes of travel along the range from one valley to the next. In many places the glacial lowering of the gaps between basins was so great that on the final melting away of the glaciers the streams found new channels of more favorable grade than those which they had formerly occupied and so were diverted from their earlier courses.

Extent of glaciation.—Exclusive of the triangular area along the northern edge of the park, bordered on the west by Stony Creek and on the south by the ridge of Birch Creek schist, this entire area was filled by glaciers during the last great ice advance, except of course the highest peaks and ridges of the mountains, which projected above the surface of the glaciers. There was, however, a very great difference in the vigor of the glaciers on the two sides of the Alaska Range. Then, as now, the south flank of the range received much more precipitation than the north flank. At present the Chulitna Basin has an annual rainfall of about 30 inches, whereas at McKinley Park station the rainfall is less than 15 inches, and in the Tanana lowland it is still less. It is fair to presume that during Pleistocene time there was a similar discrepancy between the rainfall on the two sides of the range. As a consequence, the northward-flowing glaciers reached only a moderate length. Those that moved down the Savage, Sanctuary, Teklanika, and the East Fork of the Toklat Valleys apparently failed to cross the schist ridge that lies just north of the automobile road. The outer limit reached by the main Toklat Glacier has not been accurately determined, but it probably failed to push far out onto the lowland north of the schist ridge. Muldrow Glacier, then as now, was much the largest single glacier on the north slope. It covered the lowland at the head of the McKinley Fork, spilled over into the basins of Moose Creek and Boundary Creek, and pushed westward many miles beyond the region shown on Plate 4. The glacier that descended the Nenana Valley pushed northward only a short distance beyond the area here described and terminated near the mouths of Dry and Healy Creeks.

On the south slope of the range the accumulation of glacial ice was much greater. The upper basins of the Chulitna and Nenana Rivers lay in a region of heavier snowfall and were surrounded on all sides by high mountains. From these mountains numberless valley glaciers pushed down into the lowlands, there joined into great trunk glaciers, and filled the basin brim full. The Copper River Basin, farther east, was similarly filled with ice, and that ice moved westward into the upper Susitna Basin and thence by way of the upper Nenana Valley and Jack River Valley to Broad Pass and down the Chulitna Valley, being augmented at short intervals by tributary glaciers from the Alaska Range and from the mountains to the south and east. This great glacier, at the time of its greatest extent, had an area of many thousand square miles, reached a thickness of 2,000 feet or more in the lowlands, and pushed southward past the mouth of the Susitna River far down Cook Inlet. At that time the surface of the glacier in the vicinity of Broad Pass was higher than the lowest pass northward across the Alaska Range, and a tongue of the glacier moved northward through that gap, along what is now the valley of the Nenana River, and lowered that pass by ice scour. It is owing to this unequal accumulation of glacial ice on the opposite side of the Alaska Range that we now have the unusual drainage features presented by the Nenana River and by the Delta River farther east. Both these streams head in glaciers on the south flank of the range and then turn northward to flow through canyonlike valleys entirely across a great mountain range to join the Yukon drainage system. Elsewhere, still farther east, the low gaps at Mentasta and Suslota Passes were formed across the range in the same way, but they were still high enough when the ice finally withdrew to form divides between the Pacific and Bering Sea drainage basins. Just how much of the lowering of all these passes was accomplished by glacial scour during the last ice advance we do not know. It is probable, however, that part of the erosion occurred during earlier glacial stages and that the final ice advance merely finished the task that had already been partly completed.

Retreat of the glaciers.—After the culmination of the Wisconsin glacial stage the climate gradually became less favorable to the accumulation of ice, perhaps through a decrease in the annual precipitation, and the glaciers began to shrink both in thickness and in area. The emergence of the land from beneath the ice took place by a shrinkage of the ice along its margins, by the gradual melting back of the distal edges, and by the appearance through the thinning ice sheet of mountains and hills that had earlier been entirely overridden by the glaciers. The withdrawal of the glaciers, like their advance, was not constant but was marked by oscillations forward and back, though the net result of these oscillations during the waning stage was a gradual lessening of the area occupied by the glaciers. As the shrinkage continued tributary ice streams became detached from the trunk glaciers, and they in turn melted back toward the valley heads. Eventually many valleys that had contained powerful glaciers became completely free from ice, and in others, of higher altitude or more protected exposure, only small remnants of ice persisted. The present glaciers of the Alaska Range are these remnants, and although many of them are still vigorous, others appear to be in slow retreat. In the higher parts of the range, however, glacial conditions have doubtless continued from the Pleistocene to the present.

Present glaciers.—Nearly every stream valley that heads against the main crest of the Alaska Range west of Riley and Windy Creeks contains a glacier at its head. In this region mountains less than 6,000 feet in altitude are unable to support permanent ice fields of any considerable size, and even on mountains that reach an altitude of 7,000 feet the size of the glaciers is determined by the size and direction of exposure of the catchment basins. In the eastern portion of the Mount McKinley National Park the mountains are of only moderate height and the glaciers are small. Westward the range increases in height and the glaciers are longer. Thus in the upper Sanctuary Basin there are numerous small glaciers, none of which are more than 2 miles long. In the heads of the East Fork of the Toklat, the Toklat, and the West Fork of the Chulitna Rivers the larger glaciers reach lengths of 4 to 8 miles, and still farther west, where the valleys head against the lofty slopes of Mounts McKinley and Foraker, great ice streams 30 to 40 miles long and 1 to 2 miles or more wide push down to the lowlands. Muldrow Glacier, the lower portion of which is shown on Plate 4, is much the largest northward-flowing glacier of the range. Its extreme head drains from between the two summit peaks of Mount McKinley, and after cascading down to an altitude of about 5,000 feet it flows eastward for nearly 20 miles, parallel with the range through a great trough eroded along the trace of the great fault. Thence it bends sharply northward and deploys in a broad lobe at the base of the mountains. Its total length is about 40 miles. Southwest of the region here under discussion Eldridge, Ruth, Tokachitna, and Kahiltna Glaciers, tributaries of the Susitna Basin, are comparable to Muldrow Glacier in size, and some of them may exceed it. They all head in an unsurveyed region, and their upper portions are little known.

Along the portion of the range between Anderson Pass and Windy Creek can be studied the delicate balance between amount of snowfall, direction of exposure, and size of catchment basin that determines the size of the glaciers on any particular mountain. With a given exposure and altitude, the basin having the largest catchment area and receiving the most snowfall will nourish the largest glacier. But with an unfavorable exposure a basin may be able to maintain only a small glacier, even though favored in the other respects. In this region the south slope of the range receives the most precipitation, but that is offset, through most of this distance, by the small size and southern exposure of the southward-facing valleys. In consequence, the glaciers that drain to the Toklat, Teklanika, and Sanctuary Rivers are on the average larger than those that drain to the Chulitna and Bull Rivers and Cantwell Creek. Farther southwest the heavier snowfall and larger catchment basins of the glaciers that drain the Mount McKinley mass more than compensate for their less favorable exposure, and the southward-facing glaciers are much larger than those in the smaller and drier basins that face to the north and northwest.

Glacial deposits and terrace gravel.—Within high mountains, such as occupy most of this region, the glaciers during the last ice advance were vigorous, and they profoundly affected the valleys through which they moved, but their tendency during their greatest development was to erode rather than to deposit, and most of the detritus picked up by the ice was carried beyond the borders of the area here described. During the waning stages, however, when the ice edge was being melted back farther and farther toward the valley heads, considerable glacial débris was deposited, especially in the lowlands. Here it was spread out as a sheet of variable thickness, in places as a veneer conforming to the surface of the underlying bedrock, elsewhere in an irregular, rolling topography of many scattered lakes separated by rounded ridges or hummocks. Distinct terminal moraine festoons, formed at the edge of the ice during some halt in its retreat, are rare in this area.

On Plate 4 the glacial deposits and associated outwash gravel are shown only where they are sufficiently thick to mask the bedrock geology over considerable areas. Every valley in the region contains some glacially handled débris, but on a map of the scale here used it is impracticable to show small patches of morainal material. The larger moraine-covered areas include, on the north slope of the range, the broad, rounded ridges between Muldrow Glacier and the McKinley Fork on the south and the North Fork of Moose Creek on the north; the rolling ridges along the north flank of the foothills from Stony Creek eastward; and smaller areas in such basins within the mountains as that of Polychrome Pass and on the Teklanika, Sanctuary, and Savage Rivers both above and below the Birch Creek schist ridge. There are also extensive deposits of glacial material along the main valleys of the Nenana River and its larger tributaries. South of the range Broad Pass and the broad lower basins of tributary valleys are coated with a mantle of glacial débris and are dotted with lakes that occupy depressions left in that material by the ice as it finally withdrew from over this lowland. In most of the areas here shown as containing glacial deposits and outwash and terrace gravels the nearly continuous cover of vegetation has rendered it impossible to differentiate sharply between morainal matter deposited directly by the ice and glaciofluvial deposits consisting of morainal material that has been reworked and sorted by streams. A single color has therefore been used on the geologic map (pl. 4) to include all the material deposited by the ice and by glacial streams, with the exception of the present stream deposits. As glaciers have existed continuously in this region from Pleistocene time until the present, no consistent separation can be made between the Pleistocene deposits and those of recent age.

The terrace gravel includes deposits that are related to the present topography, that were laid down during or since the retreat of the Wisconsin glaciers, and that now lie above the level of the present streams, even when they are at flood stage. These deposits form terraces along the stream valleys and also extend into the interstream areas in the lowlands along the flanks of the range and in the broader, open basins within the range. The term "terrace gravel" is here used to distinguish these deposits from the much older Nenana gravel and from the deposits of the present streams.

The terrace gravel deposits are stream laid and resemble the deposits now being made by the present streams in composition, structure, and degree of assortment. They consist primarily of well-rounded pebbles, varying considerably in coarseness from place to place, intermingled with which are considerable sand and silt, both as an interstitial filling between the pebbles and in irregular beds and lenses. In general, the deposits of terrace gravel are undeformed, and their surface slopes are the slopes of deposition, somewhat modified by subsequent erosion. Their topographic position indicates that they were laid down by streams that followed in a general way the courses of the present drainage lines, but they have been left in their present elevated positions by the lowering of the adjacent stream valleys through normal stream erosion. The terrace gravel is commonly little oxidized; it maintains its original grayish color and thus is distinguishable from the thoroughly oxidized and yellow Tertiary gravel. In most exposures examined the deposits are not very thick, though they range from 2 or 3 feet to 20 feet or more, but they cover wide areas to a depth sufficient to hide the underlying deposits. Locally the character of the terrace gravel is strongly influenced by the character of near-by materials from which it was originally derived. Thus, near deposits of the Tertiary Nenana gravel, gravel that is obviously related to the present stream channels consists of oxidized and yellow materials that closely resemble the Nenana gravel in appearance. In places where the Nenana gravel is tilted or folded the distinction between it and the much younger terrace gravel is easily made. In other places, where both are nearly flat-lying, the discrimination must be based on physiographic evidence.

The general physical condition and the physiographic relations of the deposits of terrace gravel indicate that in part at least they are composed of outwash material laid down beyond the ice border during the last stage of Pleistocene glaciation. At some places they consist of material brought from a distance by streams. At others they are composed largely of material derived locally and rehandled and reshaped into new physiographic forms by streams but moved no great distance from its source.

The fact that a single stream valley may have a series of terraces, one above the other, shows conclusively that the material composing those terraces differs considerably in age, the lowest being the youngest and the highest the oldest. Such stream terraces have no doubt been continuously in process of formation from Pleistocene time until the present, and the terrace gravel therefore differs in age and includes Pleistocene and Recent.

PRESENT STREAM GRAVEL

The gravel of the present streams was laid down under conditions essentially like those that prevail to-day in the region. The material includes only the gravel deposits that occupy the channels and flood plains of the present streams and that may be overflowed in periods of high water. As most of the streams in these mountains have relatively narrow valley floors confined between high mountain ridges, or where they flow through lowlands have intrenched themselves into the unconsolidated materials there, the stream gravel appears on the map (pl. 4) as long, narrow bands that follow the windings of the stream valleys. All the streams, even the smallest, have some gravel in their beds, but only in the larger valleys are these deposits of sufficient area to be shown on a map of this scale.

The width of the belt of gravel along any stream depends in large measure on the size of the stream, the configuration of the valley floor, and the amount of load that the stream is moving. The larger streams in this region are fed mainly by the waters of melting glaciers and are heavily loaded with débris, so that as a consequence they have built up wide gravel flats over which they flow in many branching channels. The McKinley Fork of the Kantishna River, which drains from Muldrow Glacier, is a conspicuous example of a glacially loaded stream, and its gravel bars are extensive. The Toklat, the East Fork of the Toklat, the Teklanika, and the Sanctuary Rivers, on the north side of the range, and the West Fork of the Chulitna and Bull Rivers and Cantwell Creek, on the south side, all exhibit the tendency of glacially fed rivers to develop broad outwash gravel deposits. The main headwaters of the Nenana River, although receiving much glacial drainage, have dropped much of their load in their upper basins. In this area the Nenana River is intrenched in a narrow gorge, and its gravel deposits are narrow. Farther north, beyond the confines of the mountains, its gravel deposits widen.

All glacial streams tend to drop their coarsest materials near their heads, and the stream gravel under normal conditions becomes progressively finer downstream. That general rule applies to the rivers of this region, but as nearly all of the Mount McKinley Park lies within a region of high mountains, the streams commonly flow over coarse gravel bars.

ECONOMIC GEOLOGY

METALLIFEROUS DEPOSITS

General features.—The region embraced in this report at present contains no producing mines, and the only output of minerals in the past was a small amount of placer gold that was mined on Bryn Mawr Creek, a tributary of the West Fork of the Chulitna River, in 1909. Indeed, the interest shown by prospectors in this area, as well as the number of mining claims on which work was being done, was very much less in 1930 than it had been 15 years earlier. The history of prospecting, so far as it is known, can be briefly summarized. Placer gold was discovered on Valdez Creek, a tributary of the Susitna River 60 miles east of Cantwell, in 1903, by prospectors who entered the region from the southeast by way of the Copper River Basin, and it is likely that some of them, working westward from Valdez Creek, found their way into the upper Chulitna Basin soon afterward, but they left no record of their travels. In 1904 and 1905, after the discovery of the Fairbanks placers, several men pushed southward from the Tanana River to the Alaska Range and found gold in the Kantishna district. Within the next few years another group of prospectors, including John Coffee and Frank and Alonzo Wells, reached the West Fork of the Chulitna River, mined a small amount of placer gold on Bryn Mawr Creek, and staked lode claims, on which they did assessment work for many years. At that period this whole region was very difficult of access, either from the coast on the south or from the Tanana River on the north, and almost all the pioneers who reached it came in by dog sled during the winter, when the large rivers not only offered no obstruction to travel but indeed furnished the easiest routes to follow. These men, most of whom had scanty resources, subsisted by trapping during the winter and prospected when opportunity offered during the summer months. Some of them showed a sustained interest in lode deposits, but placer gold diggings offered the only chance for them to realize a quick profit from their prospecting, and no valuable placer deposits were found on the southern slope of the mountains. In the Kantishna district, however, placer mining was continuously carried on, and that camp furnished a point of departure for prospectors in the northern half of this region. Many claims on gold, silver, and antimony lodes were staked in the Kantishna district, and development work has been continued on some of these lodes ever since.

In 1915 the route of the Government railroad, from the Pacific coast to Fairbanks, was selected, and the route chosen ascended the Susitna and Chulitna Valleys to Broad Pass and thence followed the Nenana River across the range to the Tanana River. The selection of this route greatly stimulated prospecting in the upper Chulitna Basin, and in 1917, when that district was visited by the writer,[39] there were fifteen or twenty men vigorously engaged in prospecting the lodes of the upper Chulitna.

In 1921 and 1923 shipments of high-grade silver-lead ore aggregating about 1,200 tons were made from the Kantishna region, and about that same time promising lodes of silver-bearing galena were found on Copper Mountain, now called Mount Eielson, and these events resulted in a period of renewed activity in prospecting along the north slope of the range near Mount McKinley. Yet in spite of these recurrent waves of prospecting, no lode mine within this whole

[39] Capps, S. R., Mineral resources of the upper Chulitna region: U. S. Geol. Survey Bull. 692, pp. 207–232, 1919.

region has been continuously operated for any long period, no actual production has been made except the small tonnage of ore from the Kantishna, noted above, and a few small subsequent shipments, and within the area here treated no lode shows prospects of being productive in the near future.

Some description was given by the writer [40] of each of the prospects in the Chulitna Basin on which development work was in progress in 1917. With the exception of two groups of claims, all those prospects have now been abandoned, and in 1930 only a single prospector was keeping up his assessment work on lode deposits in that basin, and one coal prospecting permit was operative. On the north side of the range the only claims in this area on which any work was being done are a group of claims on Mount Eielson (Copper Mountain), another near by on Thorofare Creek, and one in the Teklanika Basin. Only assessment work was being done on any of these lodes. Yet in spite of these facts it is not safe to conclude that no mines will in the future be developed in this region. Assays from lodes in the Chulitna Basin indicate a considerable tonnage of ore that carries gold in amounts not far from sufficient to encourage its development. It is possible that higher-grade ore bodies will be found. The Mount Eielson area contains extensive bodies of mineralized rock with large amounts of zinc ore and smaller bodies of galena of high silver content. Similarly, in the Kantishna district there are many veins carrying gold, silver, lead, zinc, and antimony, the development of which is held back only by their distance from the railroad and the resulting cost of transportation.

The lodes of the Mount Eielson area and the Kantishna district were visited in 1930 by F. H. Moffit, and the reader is referred to his description of those properties (pp. 310–334). The lode prospect reported in the Teklanika Basin has not been visited by any representative of the Geological Survey, and nothing definite is known as to the character of its mineralization.

On the south side of the range the only mineral deposits on which significant work has been done are two groups of claims in the basin of the West Fork of the Chulitna River. These deposits were visited by the writer in 1917, and his description [41] written at that time is adequate except for the small amount of assessment work done on the claims since.

Riverside group.—The Riverside group comprises several claims that lie along the southwest side of the West Fork of the Chulitna River about 2 miles above the mouth of Colorado Creek. All development work on the claims is at the base of a steep rock bluff, near

[40] Capps, S. R., op. cit. (Bull. 692), pp. 221–232.

[41] Idem, pp. 225–227.

the edge of the present stream flat, or at the upper edge of a gravel terrace that lies about 10 feet above the gravel bars. It consists of a number of open cuts, short tunnels, and a shallow shaft, most of which are now caved. The rocks exposed consist of sediments of Triassic age, including steeply dipping green to red tuff, with which are associated pale-pink, green, and blue-gray chert, locally banded, and rusty gray and white marble, all being cut by numerous dikes and sills of hornblende basalt porphyry and altered dacite porphyry. The tuff is hard and dense and ranges in texture from fine to very coarse. The marble and chert are less abundant but occur in several of the open cuts. All the sedimentary materials are more or less altered by contact metamorphism, as the result of their intimate intrusion by the dike rocks.

The openings that have been made on the mineralized zone are unconnected, most of them are caved, and the surface between them is covered with vegetation, talus, and loose material, so that the actual continuity of the mineralization can not be traced, and the general relations are obscure. The most recent work on this property is an open cut that runs 30 feet into the hillside from the edge of the stream flat and has a face 20 feet high, of which 15 feet is in rock and the rest in loose surface material. The mineralization has introduced masses and scattered grains of arsenopyrite, pyrrhotite, chalcopyrite, and pyrite, with possibly a little sphalerite, that occur over a width of 6 feet in a zone that apparently strikes about northwest and dips 20° NE. This cut and the older workings are all about in line, and they evidently indicate a mineralized zone with a northwest trend that lies in a bed of metamorphosed limestone along which is intruded a dike of dacite porphyry, with another hornblende basalt porphyry dike near by to the west. Under the microscope the vein rock in which the sulphides occur shows quartz, diopside, calcite, garnet, chloritized biotite, and hornblende, with quartz the most abundant gangue mineral. It was apparently formed by the replacement of marble or other calcareous sediments by mineralizing solutions that were related to the associated dike rocks. An assay of the heavy sulphide ore showed, in addition to small amounts of gold, silver, and copper, over 8 per cent of arsenic, indicating that arsenopyrite is the dominant sulphide in that specimen. Other assays have showed promising amounts of the precious metals.

Golden Zone group.—The Golden Zone group includes several claims in the upper basin of Bryn Mawr Creek, at an altitude of about 3,300 feet, 1,200 feet above the bars of the Chulitna River, and well toward the top of the ridge that separates the West Fork of the Chulitna River from Long Creek. The claims were staked in 1912, attention having been attracted to this locality by the presence of a large hill in which the rock is oxidized to a rusty red and is conspicuous for a long distance. This hill is composed of a mass of altered acidic intrusive rock that cuts an assemblage of materials including tuff, marble, and shale. It lies along the same general strike as the mineralized zone at the Riverside group and several other prospects in the Colorado Creek Basin on which considerable prospecting has been done. This zone is parallel to the structural trend of the Triassic beds in this locality and suggests that the mineralization occurred along some bed or group of beds that were particularly susceptible to the influence of mineralizing solutions emanating from the acidic intrusive rocks and that these favorable beds were calcareous. At the Golden Zone the intrusive rocks are impregnated with scattered specks of sulphides, but locally the rock is cut by many small quartz veinlets. In places the intrusive material is massive, but in the more intensely mineralized portion it is much altered and is jointed into slabs 3 to 8 inches thick, separated by layers of pulverulent material stained by iron oxide and copper carbonate. In 1930, at the time of the writer's visit to that part of the area, unusually heavy snows were late in melting, and in late June the openings on the property were still snow filled and inaccessible. The owner reported that only the necessary assessment work had been done on the property since the writer had last visited the claims, in 1917, and that the showings on the mineralized lode are essentially the same as at that time, with the addition of several long open cuts. In 1917 the work done included many small surface cuts, one large open cut 120 feet long, and 221 feet of underground workings. The large open cut shows altered and rusty intrusive rock that contains disseminated sulphides and a little quartz, and an average sample through the whole cut is said to have yielded an encouraging amount of gold and silver. The tunnel, which was driven in a northwest direction on the slope of the hill toward Bryn Mawr Creek, was straight for 137 feet and at a point 82 feet from the portal had a crosscut to the southwest 84 feet long. The main tunnel was driven through an altered and generally decomposed mass of dike rock in which iron and copper sulphides are disseminated and are especially abundant along cracks, joints, and slip zones. Some bunches and stringers of quartz are present in the dike rock. The crosscut follows a slip zone which contains gouge. Some white to buff soft calcareous material was also excavated from the tunnel. The metallic minerals that have been recognized on this property include arsenopyrite, pyrite, sphalerite, chalcopyrite, galena, malachite, and probably stibnite, and assays show the presence of gold and silver. A sketch map of the workings on this property, with assay plan, prepared by B. D. Stewart for the Territory of Alaska, shows widely distributed gold and silver within the mineralized area, individual assays ranging from a trace to 2.58 ounces of gold and from 0.10 to 11.60 ounces of silver to the ton, and as much as 33 per cent of arsenic.

COAL

Coal-bearing Tertiary rocks are widely distributed in this area, though generally in small tracts. There are many places in the broad valley of which Broad Pass is a part where coal beds are known, though most of that lowland is covered with glacial deposits and gravel. No doubt the actual area of the coal formation beneath the unconsolidated surface materials is considerable, and wherever these beds are exposed they almost invariably contain coal. On the north slope of the range small areas of the Tertiary coal-bearing formation occur on the Nenana River, in Sable, Polychrome, Highway, and Thorofare Passes, at several places on the head of Moose Creek, and in the depression near the junction of the Teklanika and Sanctuary Rivers and thence eastward to the Savage River. This last-mentioned locality contains the largest known area of coal-bearing beds in the region here described and also appears to have the most coal. A little farther to the north and east, however, are the much more extensive coal fields of Healy, Hoseanna or Lignite, and California Creeks, with their astonishingly numerous and thick coal beds. These areas are adjacent to the Alaska Railroad, and their accessibility has led to their development, so that coal mining is now actively carried on at Healy Creek.

Most of the coal exposures in this general region have already been described [42] in as much detail as our present knowledge justifies, and those descriptions will not be repeated here. All these coals can be classed as subbituminous or as high-rank lignites. They make satisfactory fuel for domestic use and are now extensively used in the Fairbanks district for raising steam in the power plant. Within the area here described the coals have their principal present value as a source of fuel for local use, the wide distribution of the coal deposits making the coal accessible within a reasonable distance of almost any point in the region. None of the outcrops has had more than the most superficial work done upon it, and none has yielded more than a few tons of coal, taken from the surface or from shallow workings on beds that had natural outcrops.

[42] Capps, S. R., The Bonnifield region, Alaska: U. S. Geol. Survey Bull. 501, pp. 54–62, 1912; The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 109–113, 1919. Martin, G. C., The Nenana coal field, Alaska: U. S. Geol. Survey Bull. 664, p. 54, 1919.

THE KANTISHNA DISTRICT

By Fred H. Moffit

ABSTRACT

The Kantishna distict is one of the older Alaskan mining districts which has been examined by Federal geologists and is described in several earlier bulletins of the United States Geological Survey, but it was revisited in 1930 in order to learn of late mining operations and the possibility of developing tonnage for the Alaskan Railroad. The district took prominence on the discovery of placer gold in 1905 and experienced a stampede of some proportions, but the area of the gold-bearing gravel was small, and the production of placer gold has diminished till it is now only a few thousand dollars a year.

Attention was early directed to lode deposits, and a number of promising prospects were discovered and have been partly developed. The lode deposits include high-grade lead-silver-zinc deposits, gold quartz veins, and antimony deposits. During the time of high silver prices following the World War lead-silver ores were mined and shipped to the smelter. Only the richest ores could be mined, for the cost of freighting by sled, railroad, and steamship was high. The sulphide of antimony, stibnite, was also mined at one locality, but the fall in the price of antimony coupled with the high cost of transportation prevented the shipment of any of this ore. Copper and coal may possibly become of economic value in the future, although the known coal deposits are of less extent than in fields nearer to transportation and a market, and consequently the coal is unlikely to have more than a local use. Development of the resources of this district has been retarded by its remoteness and the lack of transportation facilities.

INTRODUCTION

The Kantishna district takes its name from a tributary of the Tanana River, the Kantishna River, which receives most of its waters from the north slope of the Alaska Range in the vicinity of Mount McKinley. The district is situated at the head of the stream and includes a small part of the Mount McKinley National Park, although most of the area here considered lies outside the park boundaries. In a slightly more restricted sense the term has been applied to the Kantishna Hills, a distinct group of mountains lying between the upper Kantishna River and its tributary, the Taklat River. The Kantishna mining precinct, however, includes the larger area.

This district came into notice with the discovery of placer gold on Glacier, Friday, and Eureka Creeks in 1905. It has had a varied mineralization, and in addition to placer gold, the first product of the district, prospects have been found for silver, lead, zinc, antimony, copper, and possibly other metals. It yielded a small amount of silver and lead during the period of high prices that followed the World War, but its development as a mining center has been hindered in recent years by the lower prices of the metals other than gold, the remoteness of the district from centers of trade, and the lack of adequate transportation facilities.

Prior to 1930 the district had been visited by several geologists from the United States Geological Survey, including Brooks,[1] Prindle,[2] Capps,[3] and Smith,[4] and had been mapped topographically by Giffin. Some account of the geology or the mineral resources was given by each of these geologists, but the description by Capps is the most comprehensive and instructive, for it was based on more extended field work than any of the others, and it has been used freely in preparing this report.

The work that forms the basis of this report was undertaken primarily to get information of the present state of mining in the Kantishna district, in the hope of rendering some assistance in the solution of the problem of procuring tonnage for the Alaska Railroad and of developing the territory adjacent to it. The study of areal geology was made subordinate to the study of mineral deposits, and considerably less attention was given to gold placers than to lode deposits. Having limited the scope of the work in this way, the writer made an attempt to examine all the mineral prospects of the district which were reported to him as showing promise and devoted nearly six weeks of the early summer of 1930 to their study. He wishes to make special acknowledgment for the assistance and many courtesies extended to him during the course of the summer by Col. O. F. Ohlson, of the Alaska Railroad, Mr. Harry J. Liek, of the National Park Service; and Mr. M. C. Edmonds, of the Alaska Road Commission. The help they gave expedited the work in many ways and in particular reduced greatly the difficulties of travel in the field. He also wishes to express his appreciation of the service rendered by his two camp assistants, Messrs. M. J. Knowles and J. M. Dolan.

LOCATION AND AREA

The Kantishna Hills consist of a group of mountains lying between the Toklat River and Stony Creek on the east and the Bearpaw

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 19, 1911.

[2] Prindle, L. M., The Bonnifield and Kantishna regions: U. S. Geol. Survey Bull. 314, pp. 205–226, 1907.

[3] Capps, S. R., The Kantishna region, Alaska: U. S. Geol. Survey Bull. 689, 1919.

[4] Smith, P. S., contributed notes in U. S. Geol. Survey Bull. 755, pp. 41–42, 1924.

River and Moose Creek on the west. (See pl. 4.) The two rivers are direct tributaries of the Kantishna River. The "hills" extend north-northeastward for slightly more than 40 miles from the bend of Moose Creek north of Wonder Lake. They have a width of about 25 miles at the south end but narrow to 10 miles at the north end in the vicinity of Chitsia Mountain. For the purpose of this study the most noteworthy part of this area is the southern part, which is drained chiefly by the Bearpaw River and Moose and Clearwater Creeks. The group of cabins on the east side of Moose Creek near the mouth of Eureka Creek, which was named Eureka by the first prospectors, is about 30 miles almost directly north of the summit of Mount McKinley and 7 miles beyond the boundary of Mount McKinley National Park. This point may be considered headquarters for the district, although the Kantishna post office has been moved from Eureka to Glen Creek.

Geographically the mineralized district may be regarded as including two minor areas—the Kantishna Hills and a part of the north slope of the Alaska Range, which is separated from the hills by a wide river valley that trends east and west.

The Kantishna Hills are outliers of the great Alaska Range on the south. Their highest point is 4,960 feet above the sea, and they rise 2,000 to 3,000 feet above the broad monotonous lowland that lies to the north and west. They are less rugged than the mountains on the south, their ridges are broader, their contours are more rounded, and they are wholly lacking in permanent snow fields and ice streams. In contrast, the mountains south of the McKinley Fork rise abruptly from the lowland and within 10 miles attain an altitude of 17,000 feet, the ridges are narrow and serrate, and the streams that drain the area are fed by numerous glaciers.

The largest stream of the district is the McKinley Fork of the Kantishna River, which has its principal source in Muldrow Glacier. Muldrow Glacier drains the northeast side of Mount McKinley and is an ice stream of large size and remarkable form. It first flows east-northeast, under the control of the structural features of the range, then turns at right angles along the west side of Mount Eielson, and finally makes another left-hand turn to the west before its forward progress is ended. The total length from a point near the summit of Mount McKinley to the gravel bars of the McKinley Fork is about 40 miles. The lower end, where the traveler going through the park meets it, is stagnant, covered with débris and partly overgrown with vegetation.

The McKinley Fork first flows west from the end of Muldrow Glacier, then makes a wide sweep to the north around the Kantishna Hills, and finally takes a meandering course north-northeastward to the Tanana River, joining that stream at a point that is considerably east of the most easterly point of Muldrow Glacier. The westward-trending part of the river flows for 25 miles over a wide gravel flood plain, beyond which the northward course is begun and the stream is confined for a few miles by a rock-walled canyon that opens out again into the lowland area. The air-line distance from the canyon to the Tanana River is approximately 100 miles, but the river probably covers twice that distance in its slow meandering course across the lowland. The upper river between Muldrow Glacier and the canyon is a braided stream, dividing into numerous channels and spreading over the bars so that it is not difficult to ford with horses at most stages.

The next largest stream after the McKinley Fork is the Toklat River. It heads in the Alaska Range east of Mount McKinley and its tributaries drain the east side of the Kantishna Hills. The largest of them are Clearwater Fork and its tributary Stony Creek. Most of the drainage of the southern part of the Kantishna Hills is provided by the Bearpaw River or its tributaries and Moose Creek. This last-named stream heads against upper Stony Creek but flows west and then north around the Kantishna Hills in a course rudely concentric with the McKinley Fork. The principal streams coming into the McKinley Fork from the south and draining the north slopes of Mount McKinley are Clearwater Creek and its tributaries the Mud River, Slippery Creek, and Birch Creek. Clearwater Creek, as its name implies, is not a glacial stream. The Mud River is the stream from Hanna Glacier. It is heavily loaded with silt and in some stages is difficult to cross with horses, although it ordinarily offers little trouble and is crossed on foot by those familiar with the crossings.

ROADS AND TRAILS

The route now most frequently followed in reaching the Kantishna district is the road and trail that lead through Mount McKinley National Park from McKinley Park station to Muldrow Glacier and thence to Moose Creek by way of the McKinley Fork and Wonder Lake. The road is under construction by the Alaska Road Commission and was planned as a means for opening Mount McKinley Park to the public. In 1930 it was completed and open for use by automobiles or other vehicles as far as the East Fork of the Toklat River, a distance of 41 miles. Beyond that stream much of the preliminary work was completed as far as Stony Creek, and it was expected that by the end of the working season of 1931 the road would be ready for use as far as Muldrow Glacier with the exception of the bridge over the Toklat River. This road extends west from the railroad station to the Teklanika River, where it turns south and follows the Teklanika and Igloo Creek to Sable Pass; thence it follows a succession of low passes—Polychrome, Highway, and Thorofare. Eventually it will doubtless be extended to the McKinley Fork and will be connected with Moose Creek. This road was laid out so as to take advantage of opportunities for giving the best views of the scenery to park visitors and in consequence has grades and curves that would not have been necessary if it were designed solely for heavy commercial traffic. A road intended primarily for the development of the Kantishna mining district would probably have been started from a point on the railroad farther north and possibly would not have entered the park. If a railroad is built into the district at some future time it will almost certainly follow some route more nearly like that of the winter road from Kobe. The new automobile road will doubtless divert most of the traffic from the older routes, although it may not be as favorably situated for winter travel.

At least two principal routes were formerly in use. The first prospectors entering the Kantishna district started out from Fairbanks as headquarters and established lines of communication with that place which have been followed with little change until the park road was undertaken. During the open season the Kantishna River is navigable for small steamers from the Tanana River to a point 40 miles north of Eureka, which was named Roosevelt. A wagon road was built by the Alaska Road Commission from Roosevelt to Bear Creek, a distance of 15 miles, and is continued as a trail to Moose Creek and Eureka. This river route and the road were used for transporting supplies to the camps and ore from the camps to the Tanana River. Much of the freight for the camps, however, has been brought over a winter sled road which leaves the Nenana River near Kobe, on the Alaska Railroad, and runs southwest across the lowlands north of the mountain to Diamond, at the junction of Moose Creek and the Bearpaw River, and thence south to Glacier and Eureka. Part of this trail has been traveled regularly to McGrath, on the Kuskokwim River. It was not used in the summer.

Although the river furnished transportation in summer, most of the supplies used in the Kantishna district up to recent times were carried by dog sled in winter. This method is slow and costly and could not be employed economically for hauling low-grade ore. Probably it will soon be displaced altogether by better methods. The automobile will reduce both the time and expense of carrying freight, and already the airplane has been employed in ordinary traffic as well as in the emergencies that involve life or health. As yet there are no adequate landing fields in the Kantishna district, but planes have been brought to earth and have taken off from the gravel bars of several streams both in the park and outside it. A very good field has been established at the Savage River camp, about 12 miles from McKinley Park station. Other landing places that have been used are the gravel bar near Muldrow Glacier northwest of Mount Eielson (Copper Mountain) and the bar of Moose Creek below Friday Creek.

GEOLOGY

The geology of that part of the Kantishna district which is under consideration is simple in respect to the number and distribution of the rock formations. (See pl. 4.) The structure, age, and geologic history of these formations, on the other hand, present problems which are only partly solved and will not be understood until much detailed study has been given to them. It will not be necessary, however, to consider most of these problems to get a working knowledge of the geology of the mineralized area, and for that reason only those rocks which are west of Thorofare Pass and Stony Creek need be described. The mountainous area east of Stony Creek and the lower Toklat River is much more complicated geologically. This area is part of a section of the Alaska Range which has been studied by Capps, and which he describes on pages 236–300.

Two principal groups of metamorphosed, dominantly sedimentary rocks are represented in the Kantishna Hills and the lower slopes of Mount McKinley south of McKinley Fork. These sediments are intruded by igneous rocks, which in the form of granite and quartz diorite are especially abundant in the vicinity of Mount McKinley and include some lava flows of rather minor importance. In addition to these two main groups, several areas of unaltered or only slightly altered younger sedimentary rocks are present. The unconsolidated deposits include the usual stream deposits and glacial débris of glaciated mountain areas and also older, slightly weathered gravel deposits, which locally attain a great thickness.

The Kantishna Hills, except a small area at their north end, are made up of micaceous and quartzitic schist and phyllite with some metamorphosed igneous material. The sedimentary members of this group of metamorphosed rocks were originally laid down as shale, sandstone, and a little limestone. They were intruded in places by dark igneous rocks that were originally diabase or basalt and in at least one place, Eldorado Creek, by coarse-grained light-colored quartz diorite. The sedimentary beds also include a minor proportion of interstratified greenstone that apparently represents old lava flows.

The stratigraphic thickness of the sediments is not known, although it probably is to be reckoned in thousands of feet. The original bedding planes are not conspicuous, but the schistosity is well marked, and the structural trends average about N. 60° E., or about the same as the trend of the Alaska Range in this vicinity. Quartz veins are numerous in the schist, both as lenses and stringers in the planes of schistosity and as veins cutting across them.

These sedimentary beds have been correlated with the Birch Creek schist, which in its type locality, near Circle, at the head of Birch Creek, is made up of schistose rocks including quartzite, quartzitic schist, quartz-mica schist, mica schist, graphitic schist, crystalline limestone, and calcareous schist. With these are associated metamorphic igneous rocks, such as granitic and dioritic gneiss, amphibolite, hornblende schist, and a certain proportion of sericite and chloritic schist.[5] Mertie, who has made the most recent study of the Birch Creek schist near the type locality, now regards it as of pre-Cambrian age.

The mountains that extend southwest from Mount Eielson (Copper Mountain) and form the base of the high snow-capped range on the south are made up of argillaceous and calcareous sedimentary beds which are folded and faulted but are less metamorphosed than the Birch Creek schist. They are intruded by dikes and sills of quartz diorite branching off as apophyses from the elongated quartz diorite mass that forms the eastward-trending ridge north of Muldrow Glacier. These rocks are thus described by Capps:[6]

> A third pre-Tertiary group of sediments constitutes the major element of the north flank of the Alaska Range. It is composed dominantly of black blocky argillite and graywacke, with some black slate, some thin-bedded limestone, locally siliceous, and calcareous shale and argillite, all more or less intimately intruded by dioritic rocks.

It appears probable that these rocks extend eastward diagonally through the Alaska Range and are to be correlated with a group of rocks well developed on the south side, which are regarded as certainly of Paleozoic and probably in large part of Devonian age. (See pp. 251–255.) They are much folded, extensively faulted, and in general considerably altered but have not taken on the structure of schist.

The igneous mass previously mentioned as bordering this area of sediments on the south consists largely of coarse-grained light-gray quartz diorite. Near the contacts with the sediments it commonly shows a finer texture and darker color. In places dikes of dark basic intrusive rocks cut the diorite. The quartz diorite probably played a noteworthy part in the formation of the mineral deposits. The sedimentary beds near the quartz diorite are intruded with hundreds of dikes and sills. This area forms a zone of indefinite width between the quartz diorite mass to the south and the dominantly

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[5] Mertie, J. B., jr., Geology of the Eagle-Circle district, Alaska: U. S. Geol. Survey Bull. 816, p. 14, 1930.

[6] Capps, S. R., The Toklat-Tonzona region: U. S. Geol. Survey Bull. 792, p. 83, 1927.

sedimentary rocks on the north in which mineralization took place to a notable degree.

In addition to the two larger areas of sedimentary rock there are several smaller areas within the district. At the head of the West Fork of Slippery Creek and the eastern branches of Birch Creek are black shales and banded siliceous and argillaceous rocks interbedded with basalt flows, which appear to be less altered than the sediments of the group last described to the east and south. They are possibly younger, and if so future work may show that they should be correlated with Mesozoic rocks of similar character that appear in the south side of the range. Recent work by Capps (see pp. 257–263) has shown that Mesozoic rocks are more extensively developed in the south side of the range in the Mount McKinley region than was formerly supposed, and there is reason for suspecting that the same may be true of the north side.

One other area of sedimentary rocks should be mentioned. The mountains west and north of Thorofare Pass, between the headwater branches of Moose Creek and of Stony Creek, are made up in part of two groups of sedimentary rocks that are much folded but are less altered than any of the rocks so far mentioned. These two groups are the Cantwell formation, which is described by Capps[7] as consisting of "dark-colored conglomerates, sandstones, grits, and shales, with some carbonaceous material," and a coal-bearing formation made up of "soft sandstones, clays, and gravels, generally light-colored and locally containing lignite." The Cantwell formation makes up most of the mountain mass between Stony and Boundary Creeks. The beds are distinctly shown on the mountain sides because of the differential weathering and are compressed into folds that strike about N. 60° E. The coal-bearing formation crops out in two or three elongated areas in narrow valleys that have the same trend as the folds of the beds in the Cantwell formation. These long, narrow areas represent beds of the younger formation that are infolded into the older Cantwell formation and associated volcanic rocks, and the valleys are plainly due to the more rapid weathering of the softer coal-bearing beds. The coal is a soft lignite and has been used as fuel by prospectors in this district.

The Cantwell formation and the coal-bearing formation have yielded plant remains on the basis of which both were referred to the Eocene epoch of the Tertiary. This age assignment, especially that of the Cantwell formation, may be subject to revision when more detailed field studies are made, yet it seems required by the evidence now at hand. As to the relative age of the two formations, the field evidence shows beyond question that a considerable interval

[7] Capps, S. R., The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pl. 2, 1919.

must have elapsed between the deposition of the Cantwell beds and that of the overlying soft coal-bearing beds.

The southern part of the mountain mass northwest of Thorofare Pass is composed of basaltic lava flows of undetermined age, which are exposed near the pass, and of younger rhyolitic and andesitic tuff, flows, and intrusive rocks, which are best developed in an irregular-shaped area between the basalt flows and the Cantwell beds on the north. These more acidic rocks are associated with the Cantwell sediments and are regarded as of Eocene age. Similar volcanic rocks, which include black glassy obsidian, are exposed in the mountain south of the lower end of Muldrow Glacier. The volcanic rocks are not known to be of any importance as possible producers of valuable metals. The same may be said of the Cantwell formation, but the coal-bearing formation has some value as a source of fuel for local use.

The unconsolidated deposits of the district consist of stream gravel, including the outwash of the glaciers, low-terrace gravel, which is made up of material similar to the stream gravel, older high-terrace or bench gravel, and unsorted morainal material.

In general the striking difference between the older and younger gravel deposits, aside from their position and surface form, is that the older gravel deposits, which have been called the Nenana gravel, are considerably weathered, whereas the younger gravel is fresh and unaltered. The stream and low-terrace gravels are commonly blue or gray and are not well sorted. On the other hand, the deposits of Nenana gravel in general are of a yellow or buff color, they commonly show iron staining, and they contain many pebbles and cobbles so decomposed as to fall in pieces when struck with a hammer. The material is unconsolidated or loosely cemented and in many places is well sorted, so as to produce extensive beds of sand or evenly sized gravel. The maximum known thickness of the Nenana gravel is not less than 2,000 feet. The gravel beds are locally tilted but not folded. The Nenana gravel forms an apron or fringe at the base of the mountains for many miles along the north side of the Alaska Range and is well developed in the vicinity of the Nenana River. Large deposits are found south of the McKinley Fork and west of Muldrow Glacier, around the head of Clearwater Creek, where they are overlain in places by a veneer of morainal débris. Capps [8] has shown that in most places the Nenana gravel rests conformably on the coal-bearing beds and older rocks although he recognized local unconformities, which he regards as representing local tilting, erosion, and deposition that took place during the laying down of the

[8] Capps, S. R., The Toklat-Tonzona River region: U. S. Geol. Survey Bull. 792, pp. 98–100, 1927.

Nenana beds; furthermore, that the gravel is certainly older than gravel deposits of Wisconsin age and probably older than the pre-Wisconsin deposits. He consequently concludes that they are of Tertiary age.

The present stream and low-terrace deposits are still in the process of forming. They represent the material of the channels and flood plains of creeks and rivers that are now actively engaged in attacking the solid bedrock or in undermining and reworking older gravel deposits, in transporting for short or long distances the material thus supplied, and in depositing or redepositing their loads in preparation for a possible repetition of the cycle. The most prominent examples of these deposits are the wide flood plain and bordering terraces of the McKinley Fork, but the stream gravel of most economic value, so far as is now known, is the gold-bearing stream gravel of the placer camps in the Kantishna Hills.

Unmodified glacial deposits are less conspicuous in this district than the presence of numerous living glaciers would suggest. It is true here as elsewhere that a vast quantity of material transported by the glaciers is not deposited as moraine but is contributed directly to the streams that originate from the ice or if deposited as moraine is immediately attacked and reworked and then redeposited as stream or terrace gravel. Without doubt the glaciers were once far more extensive than now. Abundant evidence of this is found both in the areal distribution of the morainal débris and in the altitude at which it appears on mountain sides and on ridges. At their time of greatest development the glaciers of this part of the Alaska Range filled their valleys and united along the front of the range to form a broad piedmont glacier. This left a mantle of glacial deposits spread over the area that the ice vacated as it withdrew. Deposits of this kind have their topographic expression in the irregular ridges and depressions, many of them occupied by ponds or small lakes, through which the traveler wends his way in traversing the high land along the front of the mountains.

Fine examples of such topography may be seen on Clearwater Creek and its tributaries. In this same area terminal moraines crossing north-south ridges between streams were noted. They are high above the stream channels and mark a temporary stand of the ice front during the period of withdrawal.

THE MINERAL DEPOSITS

GENERAL FEATURES

The descriptions of mineral prospects which follow do not include all the prospects that have been opened in the Kantishna district. The primary purpose of the investigation made in 1930 was to examine mineral deposits that were reported to have the greatest possibilities for supplying freight to the Alaska Railroad if money for their development were obtained and transportation to justify the expenditure of this money were supplied. For this reason the time available was given mostly to the lode deposits. The gold placer deposits of the district were examined and described by Prindle[9] and Capps[10] at the time of their most active exploitation. Since then no new deposits have been found, and the annual yield of gold has diminished till now it amounts to only a few thousand dollars.

The lode deposits that have offered most promise may be divided into three groups—those containing chiefly lead, silver, and zinc; those yielding antimony; and those in which gold is the principal metal. In addition some of the deposits contain copper, but up to this time practically no development work has been done on them.

The lead-silver-zinc deposits are best developed in the vicinity of Friday and Eureka Creeks and at Mount Eielson (Copper Mountain). Antimony sulphide or stibnite has been found on Stampede Creek, Last Chance Creek, Eldorado Creek, and at the heads of Slippery and Birch Creeks. Most of the gold-bearing quartz deposits are in the southern part of the Kantishna Hills, the area in which most of the placer gold has been found. Claims representing all these three groups of deposits have been staked, and development work has been done on them, but only the lead-silver group has yielded shipping ore.

ANTIMONY

Several deposits of stibnite, the sulphide of antimony, have been discovered in this district. The best known is that on Stampede Creek (see pl. 4), a tributary of Stony Creek in the Toklat River Basin. Other deposits are known on Slate Creek, one of the branches of Eldorado Creek, on Caribou Creek, and on Slippery Creek and other streams south of the McKinley Fork in the foothills between Hanna and Straightaway Glaciers. Besides these deposits, which are large enough to attract special attention, stibnite is present in smaller quantities at numerous places.

Stampede Creek.—Stampede Creek is on the east side of the Kantishna Hills about 45 miles by the most direct line from the Alaska Railroad. The stream is less than 5 miles long and occupies a narrow timbered valley; the timber, however, extends only a short distance up the slopes, leaving bare the tops of the low-rounded hills.

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9 Prindle, L. M., The Bonnifield and Kantishna regions: U. S. Geol. Survey Bull. 314, pp. 213–221, 1907.

10 Capps, S. R., The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 76–98, 1919.

The country rock is mica schist of the Birch Creek schist and breaks with a blocky fracture owing to the presence of numerous joint planes and the schist cleavage. The stibnite deposit is on the south side of Stampede Creek near the head of its valley and is 200 feet higher than the creek at the nearest point. A small cabin in the timber by the creek, about a quarter of a mile from the stibnite deposit, is the camp from which prospecting operations were carried on. This place is most easily reached by travelers from the south by crossing the ridge between Clearwater and Stampede Creeks.

The principal exposure of stibnite is a mass of high-grade ore just west of the axis of a northward-trending ridge between two small branches of the creek, deposited along a fault plane that strikes N. 70° E. and dips at a high angle to the south. The body of stibnite exposed is about 30 feet wide and 20 feet high and extends 30 feet in the direction of the vein, as is shown by an open crosscut and by an open longitudinal cut along the south side of the ore body. The crosscut, which is at the east side of the mass and is 10 feet or more deep, shows high-grade ore at each end and an intermediate part made up of veins of stibnite and quartz inclosed in the schist country rock. The west end of the mass, which appears to be in large part the original surface showing, exposes practically pure stibnite 20 feet thick in which little country rock or quartz is visible to the unaided eye. A drift was run along the south side of the ore body about 10 feet lower than the bottom of the open crosscut, and a crosscut is said to have been driven from the east end of this drift into the ore body. This drift was only a little below the original surface and is now caved, so that it furnishes no assistance in judging the size of the ore body. In addition to the drift and crosscuts that have been mentioned several shallow open cuts showing vein quartz and a small amount of stibnite were made a short distance east of the large exposure. Also two open cuts were dug and a shaft was sunk along the vein to the west. These openings are now caved so as to hide the bedrock, but the dumps indicate that no considerable deposit of stibnite was discovered. It therefore appears that the large mass of high-grade ore is definitely limited on both east and west, but there is no way other than by exploration underground to determine how far the ore body extends in depth.

In the course of the developments that have been made many tons of high-grade ore were taken out. Most of this ore was put in two piles, which the writer estimated roughly to be 30 by 15 by 3 feet and 20 by 10 by 4 feet. Besides this loose ore 100 sacks of selected material, which will probably average about 150 pounds to the sack, was made ready for shipment but was never moved from the ground.

The property has changed ownership a number of times and at present belongs to C. A. Trundy, commissioner and postmaster of the district, and associates. No development work has been done on it for some time. The high price paid for antimony during the war stimulated the opening of the deposit, but the subsequent fall in price made it impossible to mine stibnite in this district at a profit, and the work was given up.

Extension claims have been staked to the east and west, and stibnite is reported to have been found on the hills of the creek that runs a short distance west of the main deposit.

Slate Creek.—The stibnite deposit of Slate Creek occurs in an area of quartzite schist intruded by masses of light-colored coarse-grained diorite, as is seen on Eldorado Creek below the mouth of Slate Creek. This deposit has had no development work done on it for several years. It was not visited by the writer in 1930, but was examined by Capps[11] in 1916. The following description is taken from his report. The property consisted of a group of claims, but

> the work done has been confined to the driving of a tunnel 97 feet long, with 22 feet of crosscuts, and to the excavation of an open cut immediately above the tunnel. The open cut and the tunnel show a strong fissure, along which movement has taken place. This fissure strikes N. 50° E. and dips 82° SE. and forms the southeast wall of the main ore body, though a little ore is seen on its southeast side. The ore body has a maximum width of 15 feet and constitutes a reticulated stockwork of quartz and stibnite, with irregular bunches and horses of decomposed clayey schist, all much broken and confused. The inclosing quartzite schist strikes north and dips 29° E.
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> Almost pure stibnite occurs here in veinlets and in veins, the largest 2 feet thick, and in irregular lenses and bunches. In some places it is solid and unaltered, but in others it is crushed and broken and consists of small fragments of quartz and stibnite recemented by yellow and reddish secondary oxidation products, which on analysis are found to consist of the antimony ochers, stibiconite, and kermesite. The principal ore bodies, which occur within 6 or 8 feet of the main fissure, seem to lie in the stockwork with their longest diameter oblique to the main fissure, the ore lenses and veinlets in general dipping 60° NW. The stibnite occurs predominantly as aggregates of acicular crystals, but includes also masses of fine-grained material. About 125 tons of hand-sorted stibnite has been mined, most of which was taken from the open cut. That taken from the tunnel was of lower grade, as the pure stibnite occurred there in smaller bunches, and the ore contained more quartz and schist. In the absence of facilities for machine concentration much stibnite that could not be separated from the gangue by hand sorting was thrown on the dump.

Slippery Creek.—Several deposits of stibnite south of the McKinley Fork are known. One is near the head of the west fork of Slippery Creek, 7 miles west of Hanna Glacier, a little to the east of a small glacier between Hanna and Straightaway Glaciers, and approximately 2,800 feet above the bars of McKinley Fork. The rocks

[11] Capps, S. R., The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 107–108, 1919.

of this locality are black and gray banded shales and siliceous beds interstratified with lava flows, all of which are cut by fine-grained light-colored igneous dikes. These rocks are folded and faulted but at this locality are not strongly contorted. The stibnite occurs in a thin sandy bed, which is so much decomposed that its original character is obscure and it appears now as highly colored sand. It is overlain by a thin bed of black shale from 1 to 2 feet thick, which in turn is overlain by a dark igneous rock divided into angular blocks by closely spaced joints. Many of the joint faces are slickensided, and the rock is partly altered to serpentine. The highly colored oxidized bed and overlying black shale extend to the southwest, following the irregularities of the mountain face like a contour line except that they descend gradually to the level of the glacier a quarter of a mile away. The slopes of the mountain are strewn with fine fragments of shale, but are bare in places so as to show plainly the interbedded sediments and lava flows dipping southeast at a low angle. At one place the basalt was discolored and altered for a distance of nearly 2 feet on each side of a vertical eastward-trending fault plane. Blocks of stibnite a foot or more in diameter have been freed from the decomposed colored bed and are scattered with other débris on the hill slopes below the thin bed of black shale. Smaller pieces of the stibnite were dug from the soft decomposed bed.

No development work other than a few open cuts has been done on the deposit, all of which is included in the Merinser claim, the property of W. J. Shannon.

A claim called the Stibner, owned by Mr. Shannon, is on the Birch Creek side of the top of the ridge west of the small glacier. At this place a fault zone that strikes N. 20° E. cuts altered basic igneous rocks similar to those on the Merinser claim. Mineralization took place in the fault zone, resulting in the production of small veins of stibnite and another mineral that appears to be tennantite or possibly tetrahedrite.

Another claim belonging to Mr. Shannon was staked on a stibnite deposit 5 miles west of the Stibner claim, on the branch of the Straightaway Glacier that heads against the west branch of Hanna Glacier. This locality was not visited by the writer, but it is reported that the geologic conditions are similar to those at the Merinser claim and that a large body of stibnite is exposed.

SILVER-LEAD PROSPECTS OF MOUNT EIELSON

Mount Eielson, formerly called Copper Mountain, is one of the foothill mountains of the Alaska Range. (See pl. 4.) Muldrow Glacier on the west and the stream that flows along its east and north sides set it off slightly from the mountains south of it and give it a somewhat isolated appearance. The form and position of the mountain is not shown on any of the published topographic maps. The lower slopes are smooth and free of timber but are covered with grass or moss and other low vegetation. The top and ridges are sharp and rugged. It is probably between 5,000 and 6,000 feet high.

Mount Eielson is made up of sedimentary rocks intruded by quartz diorite and darker related igneous rocks. The sediments as seen in many outcrops include calcareous and siliceous argillite and thin-bedded limestone together with black schist and slate. The limestone beds are silicified in some of the exposures and are strongly banded. The thickest limestone bed examined was at least 100 feet thick. Dikes and sills of the light-colored granitic rocks cut the sediments in all directions, and their intrusion has doubtless caused much of the alteration shown by the sediments. Satisfactory exposures of the sedimentary and intrusive rocks are difficult to find on the north side of the mountain, for the slopes are thickly strewn with the débris from the intrusive rocks which masks the sedimentary rocks and creates the impression that the igneous rocks are present in much greater proportion, although this probably is not true. The hard, resistant intrusive rocks make up most of the higher part of the mountain, where they are in a position to cover the sediments of the lower slopes with waste. The best exposures of the sedimentary beds are seen in the low benches bordering the stream east of Mount Eielson and in a few gulches that trench the lower north slopes of the mountain.

The largest known mineral deposits of Mount Eielson are on its lower north slopes. Between the mountain and the glacier stream on the north is an uneven-surfaced bench approximately a quarter of a mile wide and several hundred feet higher than the creek. Many of the gulches on the mountain face end at this bench, although one or two continue across it as shallow canyons. They give the best rock exposures and consequently are places where the metallic minerals are most easily found. Approximately 30 claims have been staked along the front of the mountain and on the bench, but in 1930 assessment work was being done on only 7 of them. The most abundant metallic minerals are galena and sphalerite, which almost without exception occur together in varying proportions. Chalcopyrite occurs with these two sulphides in places, and tetrahedrite in a few places accompanies them. Gold and silver are present, and as might be expected the silver increases or decreases markedly with the galena. No complete mineral analysis of the deposits of Mount Eielson has been made, and it is possible that such an analysis might reveal the presence in small quantity of minerals or even metals not now known to be there.

Several tunnels have been started on mineralized outcrops near a gulch about the middle of the north face of the mountain, on a claim known as the Jiles claim. The lowest tunnel is 600 feet above the gravel bars at the park ranger's cabin near Muldrow Glacier. This tunnel is in loose material and caved while it was being driven, so that it failed to reveal any ore. A second tunnel 50 feet higher in the middle of the gulch is 60 feet long and was driven to the south without revealing any valuable ore body, although it is evident from the appearance of the dumps that masses of sulphides were encountered. Another 60-foot tunnel, 50 feet higher on the west side of the gulch, was driven under the discovery outcrop, which is 50 feet still higher. This tunnel does not appear to have intersected any notable ore body. A large open cut was made in the gulch opposite the discovery outcrop. The mineralized mass is a much fractured dull-brown, iron-stained rock containing sphalerite, galena, chalcopyrite, and pyrite (?). The mineralization was intense, but the proportions of galena and sphalerite differ from place to place. The sulphides occur in distinct bands, indicating the character of the original rock, which was banded limestone, now silicified so that it is almost unrecognizable.

An interesting exposure of the mineralized country rock was seen at the lower end of the gulch 200 yards south of Mr. Grant's cabin, the camp from which most of the development work on Mount Eielson has been done, and merits description because it probably is a typical example of the ore bodies found in this locality. The cabin is at the south edge of the bench and on the east bank of a small creek that comes out of the gulch a few hundred feet west of the gulch where the tunnels on the Jiles claim are situated. The northward-flowing stream emerges from a small canyon cut through contorted and silicified banded limestone that is intruded by diorite. The bedding of the limestone is nearly horizontal, and the thickness is at least 100 feet. The limestone was originally an impure limestone and is now banded with siliceous material forming thin hard beds that stand in relief on the weathered surface. In places it is finely crystallized and white. The diorite is light gray and shows fine phenocrysts of hornblende in the larger dikes. The smaller dikes are fine grained and contain little of the dark minerals.

Just inside the canyon mouth on the west side of the creek the banded limestone is cut by a vertical dike, approximately 10 feet thick, which strikes N. 34° W. On both sides of the dike, over a total width of 30 to 40 feet, the limestone is altered and impregnated with sphalerite, galena, and chalcopyrite, which, however, show a somewhat greater concentration on the east side. In some places the limestone is largely replaced by the sulphides; in others the sulphides are disseminated sparingly in grains through the country rock or cut it in small veins. On the east the contact of altered and unaltered (that is, unmineralized and unoxidized) rock is distinct but is not a sharp line, for the altered and unaltered rock weather into each other, and small veinlike apophyses of the altered rock penetrate the unaltered rock for several inches.

Outside the canyon and over a little spur, not more than 50 feet from the place just described, the banded limestone is heavily mineralized along a poorly defined vertical fault that strikes N. 85° E. The minerals decrease away from the fault but extend in small scattered grains for at least 6 feet.

On the east side of the gulch 100 feet up the stream a shallow hole was driven in a fault that strikes east and dips steeply north in altered mineralized limestone which is bordered on the upstream side by coarse quartz diorite. The same sulphides of lead, zinc, and copper are present here also but in small quantity. A small body of the sedimentary rocks included in or intruded by the quartz diorite in the cliff above the creek is also mineralized at and near the contact with the quartz diorite.

The conditions in this gulch indicate clearly to the writer that mineralization and silicification were brought about by the intrusion of the quartz diorite and that the limestone or limy shale beds were the most favorable places for the mineralization to occur. The deposits, then, are of the contact-metamorphic type and should be sought for at or near the contacts of the limy beds and intrusive rocks. Deposits of the fissure vein type are probably to be less expected than those of the contact type. The appearance of an extended vein deposit results from the association of the metallic mineralization with the calcareous beds. The strike of the banded limestone beds is a little north of east, a course which takes them along the foot of the mountain toward the gulch on the east where the tunnels were driven. It is probable, however, that a much greater thickness of sediments is involved at that locality than at the gulch near the cabin.

The numerous claims that have been staked cover a strip of ground extending from the vicinity of Muldrow Glacier to the glacier stream on the east side of Mount Eielson. They also extended up the face of the mountain in such a way as to cover much of the slope south of the cabin to a height of 600 to 700 feet above the bench. This slope is strewn with loose material, so that few outcrops of the bedrock are seen, but the débris contains a surprising quantity of float ore. The proportion of galena to sphalerite seems greater on the west end of the mineralized area and to diminish toward the east. The prospects east of the glacial stream contain much more sphalerite than galena. Tetrahedrite was not recognized in the ores from the Jiles claim but is reported from prospects nearer Muldrow Glacier.

The seven claims on the north front of Mount Eielson that were held in 1930 are the property of O. M. Grant and are considered to be the most promising among a large number formerly held. In recent years the only development work done on these claims is the assessment work required to hold them. The three tunnels and open cuts on the Jiles claim were made in the expectation of revealing high-grade silver-lead ores, which at the time the work was done were bringing a high price. Mr. Grant told the writer that a 20-foot sample from the Jiles claim assayed 6 per cent of lead, 4 per cent of zinc, 30 to 40 ounces of silver to the ton, and some gold. The silver content depends largely on the quantity of galena present. Sphalerite unaccompanied by galena carries little gold and silver. On the other hand, some assays of the galena show more than 200 ounces of silver and $6 to $17 in gold to the ton.

The mineralized rock so prominent in Mount Eielson extends in less degree eastward across the unnamed glacial stream that flows around the east and north sides of the mountain and joins the drainage from Muldrow Glacier. Up this stream, about 2 miles from the trail through Thorofare Pass, a tributary comes in from the east. The ridge south of the tributary is made up of the same succession of sedimentary beds intruded by granitic rocks as is found in Mount Eielson. Several prospects have been found on the ridge, but the one on which most exploratory work has been done is on the top of the ridge at an altitude 1,600 feet higher than the ranger's cabin near Muldrow Glacier and less than a mile from the glacial stream. The mineral deposit is sphalerite replacing impure limestone along a fault plane or shear zone in vertical beds that strike N. 70° E. In addition to the limestone and granite the débris on the mountain slopes contains much sandy shale and sandstone and a minor quantity of black shale, but no exposures of these rocks in place were seen near the mineral deposit, although they crop out in the benches bordering the stream. The ore body is fractured and appears to cut across the beds but to have its greatest extension in the direction of their strike. The maximum width of the body is 7 feet. Numerous blocks of bluish-gray limestone partly silicified and containing sphalerite are scattered through the talus in the vicinity in such a way as to indicate that they came from some near-by point but from some other outcrop than the one mentioned. No galena was seen in association with the sphalerite, so that the value of the prospect appears to lie in the zinc, but no assays for gold and silver were made. The claims covering the prospects are the property of John Anderson, who has a camp from which the prospecting and development work is done on the bars of the glacial stream near the mouth of its tributary.

OTHER MINERAL DEPOSITS IN DRAINAGE BASINS OF SLIPPERY AND CLEARWATER CREEKS

A description of stibnite deposits near the heads of Slippery and Birch Creeks has been given, but there remain to be described several deposits of other metallic minerals occurring along the mountain front between Muldrow Glacier and Birch Creek. These properties, like the Merinser and Stibner claims previously mentioned, belong to W. J. Shannon.

Several prospects in the area between Slippery Creek and Mount Eielson were also examined. They are all on the tributaries of Clearwater Creek.

Slippery Creek and its eastern branch, Iron Creek, head in the outlying mountain between Hanna Glacier and the lowland area to the north. Slippery Creek forks near the base of the mountain and receives part of its water from a small glacier that is also near the head of Iron Creek. The lower mountains along the north front of the range from Thorofare Pass at least as far southwest as Straightaway Glacier are made up of sedimentary beds that are cut by many dikes and sills of light-colored granitic rock, forming an intermediate zone between rocks on the north that are dominantly sedimentary and those on the south that are dominantly igneous. The heads of Slippery Creek and Iron Creek are in this zone.

Terminus, Greenback, Magnet, and Old Sourdough claims.—Four claims, lying end to end and extending from the south side of Slippery Creek across the intervening ridge to the east side of Iron Creek, have been staked to cover mineral outcrops. These claims are known as the Terminus, Greenback, Magnet, and Old Sourdough claims. The two on Slippery Creek will be described first.

At a point on Slippery Creek whose altitude is approximately 4,000 feet a highly colored rock bluff at the foot of a steep mountain slope forms the north bank of the stream. This bluff is the outcrop of the Greenback claim. It extends along the creek for 360 feet and is a dark schist, probably an altered argillaceous sedimentary rock, but possibly including some dark fine-grained igneous rock. This schist is cut by a vertical dike of fine-grained light-gray granitic rock without conspicuous dark minerals, which extends east and west, parallel to the creek. Branching from it are smaller masses, some of which may be faulted-off portions of the main dike. The country rock in the vicinity of the dike is mineralized and highly colored by oxidation products of the iron and copper minerals. The minerals resulting from the mineralization that were recognized were pyrrhotite, chalcopyrite, sooty manganese oxide(?), sphalerite, galena, and garnet.

Malachite, azurite, and chalcanthite have been produced by oxidation of the copper sulphides. The blue copper sulphate chalcanthite appears as a crust or as soft, easily broken deposits in shattered parts of the ore body. Black specks of manganese oxide, probably pyrolusite, are present in the light-colored dikes and in some of the ore. The development work consists of open cuts on the more promising copper showings. Good specimens of ore containing pyrrhotite associated with sphalerite and chalcopyrite are found in the loose material on the bank of the south side of Slippery Creek in places which indicate further mineralization on that side.

The Terminus claim extends up the mountain slope west of the Greenback claim. Its discovery outcrop is 700 feet above the creek on a spur sloping north. The country rock is banded siliceous and argillaceous sedimentary material, which is schistose and silicified and includes thin beds of impure schistose limestone. The sediments are interlarded with thin sills of light-colored fine-grained granitic rock from 6 to 18 inches thick and are cut by dikes of the same material. The sills are lenticular and as they follow bedding planes have the same strike and dip—that is, they strike north and dip 90°. All these rocks are much fractured and iron stained and are cut by poorly defined faults. Some of the sedimentary beds are partly replaced with sphalerite and chalcopyrite. A short distance above this exposure the sedimentary rocks disappear and the country rock becomes fine-grained granite, which in one place is cut by a black dike 6 feet thick.

The Magnet and Old Sourdough claims extend east from the Greenback and lie chiefly if not wholly in the valley of Iron Creek. The rock formations are the same as on the Slippery Creek side of the ridge. The principal exposure of the Magnet claim, which adjoins the Greenback, is about halfway from the top of the ridge to Iron Creek. A small open cut exposes a much fractured dark fine-grained rock that is silicified and iron stained. It contains pyrrhotite, sphalerite, and a little galena.

A much more extensive mineralization took place on the Old Sourdough claim. The creek has cut a steep, narrow gulch into the country rock which here includes schist, quartzite, and limestone beds, and has exposed a wide dike of light-gray porphyritic granite or diorite striking northeast, which is intruded into the sedimentary beds. This dike crosses the creek at a point whose altitude is approximately 4,200 feet. The rocks are shattered and oxidized, and a large area is brilliantly colored with the oxidation products. On the downstream side of the dike are masses of pyrrhotite, which appear as nearly pure masses of the mineral or as disseminated deposits in the country rock.

About 100 feet farther up the creek, on the north side, is a large exposure about 60 feet high, extending 100 feet along the creek. The rock is shattered and highly colored and contains much pyrrhotite, together with sphalerite, chalcopyrite, and copper carbonate. An open cut on the best carbonate showing exposes brecciated country rock cemented with azurite and malachite. The intrusive granite contains black specks of impure pyrolusite (manganese oxide), with which is associated a little chalcopyrite.

On the ridge about a quarter of a mile east of this exposure some small open cuts show a little galena and sphalerite in veins in the country rock.

Question Mark claim.—The Question Mark claim is on a branch of Slippery Creek about 1 mile west of the Greenback claim and at the same altitude, or approximately 4,000 feet. The country rock is chiefly black shale, which weathers easily into a soft black mud but shows other oxidation colors. At the locality under consideration it is cut by a dark fine-grained dike, which is porphyritic in places and contains small crystals of feldspar. The igneous rock also is much decomposed, and parts of it have broken down to gray sand and a brown hematitic mud. It contains tissue-like seams and disseminated grains of native copper together with a little cuprite. Only a small exposure of the igneous rock was seen, but traces of the copper were found in the loose material on the ridge south of it for a distance of 75 feet. No development work other than the clearing away of débris from the outcrop has been done on this claim.

Merinser claim.—The Merinser claim, near the head of the west branch of Slippery Creek, was mentioned in connection with the stibnite deposits but is referred to again here because of a showing of quicksilver. The outcrop is on a sharp northward-trending ridge at an altitude of about 5,000 feet, or 3,000 feet above the bars of the McKinley Fork. Black shale and banded argillaceous and siliceous sediments interbedded with lava flows make up the country rock. The mineralized outcrop is a dark fine-grained rock, which appears to be a much altered sediment cut by a light-gray fine-grained granite or felsite. These two rocks are in contact along a vertical fault that strikes north. The dark rock is exposed in an open cut 36 feet long on the west side of the narrow ridge and contains seams of calcite and quartz in which is a red mineral that was identified as cinnabar. Mr. Shannon informed the writer that when the open cut was begun a little native mercury was found and that a sample of the rock which he had assayed yielded 1.86 per cent of mercury. Iron and copper sulphides are present in small quantity and are made more prominent by their oxidation products in fracture planes and on the surface of the rock fragments. A brownish-red coating of hematite is particularly noticeable.

Carlson Creek claims.—Carlson Creek is one of the western tributaries of Clearwater Creek and is a small stream with two branches. Some open-cut work has been done on the Copper Lode claim, staked on the west branch of the creek. The mineralized outcrop is a ledge of the oxidized and iron-stained country rock about 80 feet long and 25 feet wide forming the north bank of the creek at a point whose altitude is about 3,600 feet. This ledge is made up of sediments, including principally a much shattered and oxidized dark fine-grained rock whose original form was not definitely determined. Probably it is an altered limy shale. With it are associated bluish-gray limestone and a breccia or conglomerate of angular granite fragments in a groundmass of the same material—that is, sand from the erosion of a granite mass. A fissure or fault that strikes N. 35° E. and dips steeply to the west passes through the outcrop. This strike is the same as the trend of the ledge and the strike of the bedrock. The west or hanging-wall side of the fault is bluish-gray limestone with small exposure. At one place the footwall side is conglomerate, but farther downstream the dark rock comes between the limestone and the conglomerate. This dark rock appears to be lenticular, and in it the principal mineralization occurred. It contains irregular masses of pyrrhotite, which is associated with a little chalcopyrite that stains the rock surfaces with copper carbonate. The ore is not continuous but is distributed along the fissure in nearly equidimensional bodies several feet across.

A little more than one-third of a mile N. 55° E. from the Copper Lode claim, on the other branch of Carlson Creek, is a second mineralized area. The outcrop is about 250 yards from the mouth of the creek, at an altitude of about 3,300 feet, and is included in the boundaries of the Galena Lode claim. At this place a mass of contorted black schist extends for 150 feet along the right side of the creek, which here runs northwest, and is included between masses of granite porphyry. The southeast boundary between schist and granite is a fault plane striking N. 60° E. and dipping steeply west. This fault is well defined, but the northwest boundary, which is also a fault contact, is so poorly shown that the observed strike of N. 40° E. and dip 90° were thought to be somewhat doubtful.

The black schist is much crumpled and is seamed with quartz veins, which lie chiefly in the planes of cleavage or schistosity. They range in thickness from a fraction of an inch to several inches. The largest observed was a foot thick, about 4 feet long, and lenticular. It contained galena, sphalerite, and pyrite.

The granite on the southeast side of the black schist is cut by a 5-foot dike of basalt containing gas cavities. This dike trends with the creek but was not seen in the schist, probably being offset by the fault.

The mineralization seems to have been greatest near the southeast side of the schist mass. The minerals present are galena, sphalerite, and pyrite, and their relative abundance appeared to be in the order given, the galena being most abundant. These minerals are present chiefly in the quartz veins but to some extent in the schist also. They were not seen in the granite.

At one place about 200 feet up the creek from the locality noted above and at several other places beyond it, the granite contains small masses of dark iron-stained rock which is slightly mineralized. These are probably inclusions of schist.

Twin Hills lode claim.—The most easterly tributaries of Clearwater Creek head in the mountains within the sharp bend of Muldrow Glacier. The Twin Hills lode claim is on the west side of a double-peaked mountain between two of these tributaries and includes a westward-trending gulch heading in the sag between the two peaks. The gulch is cut in country rock consisting of light-gray fine-grained porphyritic granite, bluish-gray banded limestone, partly silicified, and greenish-gray fine-grained rock difficult to identify because of its condition but probably an altered argillite or possibly diabase. In places the dark rock contains radiating fibrous aggregates of green hornblende. All the exposures show rocks that are cut by fracture planes or are shattered so as to form a poorly defined breccia. Mineralization of the shattered country rock has been widespread. Near the mouth of the gulch, at a point whose altitude is about 4,000 feet, a vein of sulphide material is exposed by the cutting of the small stream. The width of the vein is not well shown but appears to be not less than 10 feet. The linear extent is unknown, as the talus conceals it. This vein shows pyrrhotite, chalcopyrite, magnetite, sphalerite (?), and the green hornblende crystals before mentioned.

About 100 feet up the talus slope on the north the white porphyry is leached along a fault or fissure and is slightly mineralized. An assay sample from this place was reported to show the presence of gold, silver, lead, and zinc. The gold content was reported as $4 to the ton.

Float containing sphalerite, magnetite, and galena occurs in the gulch above this altitude all the way to the top of the ridge. Galena, however, is much less common than the other sulphides.

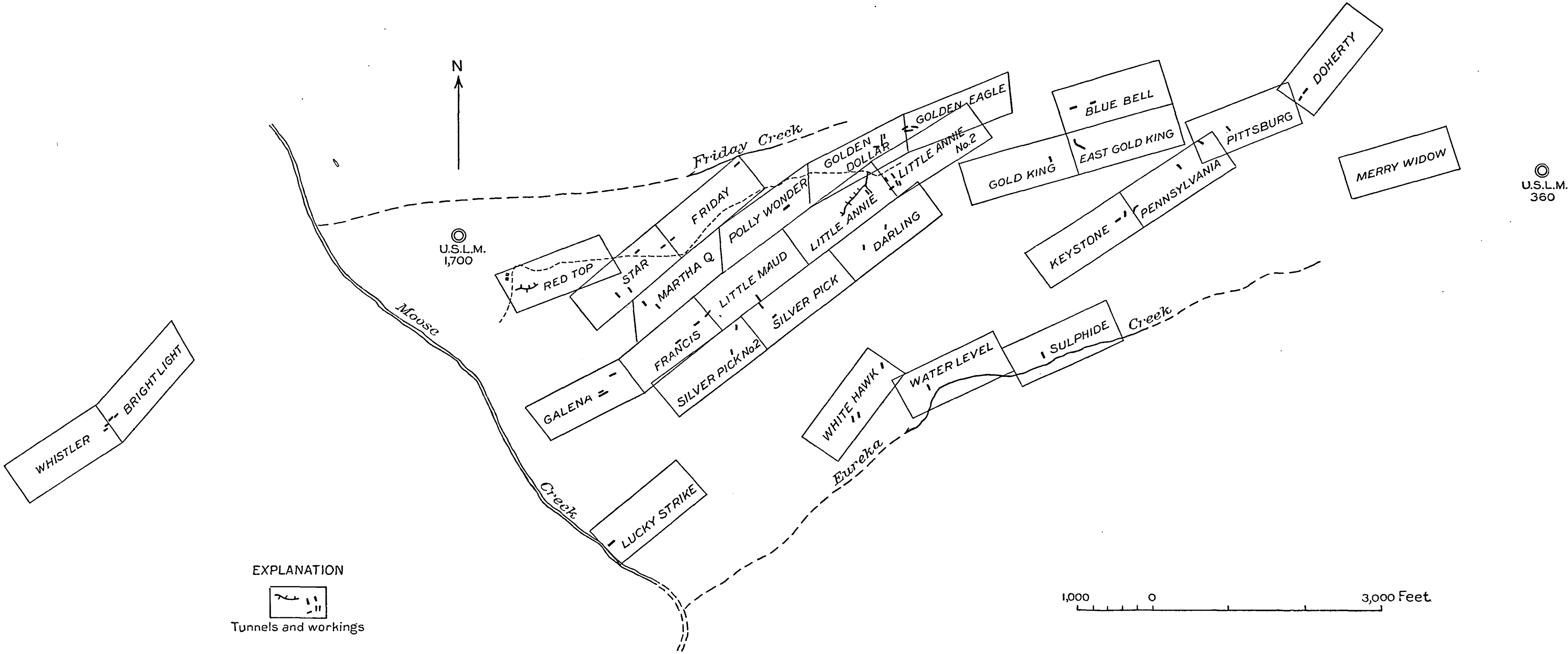
In the saddle on the ridge the dark rock, silicified limestone and leached porphyry are present and show pyrrhotite and magnetite at several places where they are cut by fault planes. Assays from these places are reported to show gold and lead.

Other prospects.—On the east side of the ridge at the level of the creek, at an altitude of about 4,000 feet, directly below the saddle, a vein of magnetite is exposed at the margin of the gravel-covered valley floor. The magnetite is the product of a replacement of the country rock along a fault plane or fracture zone, which so far as it is possible to determine from this exposure appears to strike nearly west. Where the replacement was not complete the magnetite appears as veins cutting the country rock and as disseminated material. The magnetite is associated with a little copper appearing as chalcopyrite and as copper stain. The width of the vein is apparently between 20 and 30 feet but was not determined with accuracy, as the boundaries are not definite or fully exposed. The surrounding sedimentary beds are brecciated and much stained with iron oxide.

Another mineralized fracture zone containing sphalerite crops out at the base of the hill slope 100 yards north of the magnetite vein.

The area between Clearwater Creek and the lower end of Muldrow Glacier is occupied in part by a mountain made up largely of volcanic tuff and glass, but at the north base of the mountain the older intrusive rocks appear and are followed a little farther north by large deposits of Nenana gravel and glacial till. The volcanic rocks are not known to be mineralized. The intrusive rocks, on the other hand, are highly colored by iron oxide and are mineralized to some extent. A gray granitic intrusive rock predominates but is associated with a fine-grained white intrusive rock filled with tiny crystals of pyrite. The intrusive rocks are cut by a zone of highly colored brecciated rocks, trending N. 60° E., which is filled with veins of quartz and calcite and is reported to carry a small quantity of gold. The outcrop, which extends for several hundred feet, has been staked, but no development work other than a surface cut has been done.

So far as is known to the writer, all the claims between the head of Clearwater Creek and Birch Creek on the north slopes of the Mount McKinley mass are owned by W. J. Shannon. Mr. Shannon's base camp is on Slippery Creek near the upper limit of spruce timber, but he also has a permanent cache on the bars of the McKinley Fork south of Wonder Lake. In 1930 he also had a temporary cache of supplies on the head of Clearwater Creek, which was made necessary because of the early break-up of winter. The supplies were brought over Anderson Pass from the Susitna side of the range by dog team, and part of them had to be left on the head of the Clearwater when the snow dissappeared. In 1930 Mr. Shannon laid out a trail from his cache south of Wonder Lake to his camp on Slippery Creek. This



MAP OF LODE CLAIMS IN THE VICINITY OF FRIDAY AND EUREKA CREEKS trail runs in the timber on the north side of the McKinley Fork to a point opposite the mouth of Clearwater Creek, where a ford is made to the south side of the McKinley Fork and then to the west side of the Clearwater. Thence the trail follows the west bank of the Clearwater for a mile or more and then takes a nearly direct course southwest to Slippery Creek, crossing the Muddy River at a point 4 miles above its mouth.

Although both the McKinley Fork and the Muddy River are glacial streams and are subject to the wide range of volume common to such streams, they usually offer little difficulty to fording with horses.

A second trail was laid down Slippery Creek from the camp to the McKinley Fork and thence through the timbered lowland area east of the McKinley Fork to connect with the road to Roosevelt and the winter trail to Kobe. The marking of this trail was not completed at the time of the writer's visit, but completion before the season was over was planned.

All the prospects between Muldrow Glacier and Birch Creek are above timber line and several miles from the nearest spruce in the valleys of the McKinley Fork and its tributaries. Up to the present time the spruce has supplied mining timbers and fuel, but an undeveloped source of fuel is at hand in the small scattered areas of lignite, such as are found at several places along the new park road and have furnished coal for the camps of the Alaska Road Commission. The canyon of Clearwater Creek is reported to offer a favorable site for the production of power if future work develops a need for it.

LODE DEPOSITS OF THE KANTISHNA HILLS

GENERAL FEATURES

The lode deposits of the Kantishna Hills include gold, silver, lead, and zinc in addition to antimony, the occurrence of which has already been described. Most of the deposits now known were discovered early in the history of the district, after the failure of the gold placers to meet the first expectations of the incoming prospectors had turned those who remained to the search for lodes. Nearly all of them are in the southern part of the area, in the group of hills extending west and south from Spruce Peak to Moose Creek. Within this area the ridge between Friday and Eureka Creeks easily holds first place in respect to the number of prospects and the development work that has been done on them and is the only part of the district that has produced ore for the market with the exception of Eldorado Creek, from which a small quantity was shipped. The different prospects may be described with reference to their location—that is, the creeks near which they are situated. All of them lie within the schist area and seemingly differ little in their general geologic relations, although it can not be said that the details of the geology have been worked out. The schists are in large part if not wholly derived from sedimentary rocks but were intruded in several places by granular igneous rocks. The character and form of the mineral deposits suggests two periods of mineralization—one in which the gold quartz veins were formed and a second in which the silver-lead deposits were formed. It seems clear, furthermore, that oxidation and enrichment of some of the ore bodies occurred also and thus helped to produce the wide range in value of the ores.

FRIDAY CREEK

The ridge between Friday and Eureka Creeks is a notable site of mineralization. Most of the better-known claims of the district are included on it, and although some of them are on the Eureka Creek side they are all described under one heading. This ridge is a long, smooth, round-topped mountain without timber and reaches an altitude of 3,680 feet near the head of Friday Creek, or about 2,300 feet above the mouth of the creek. Most of the claims on Friday Creek, especially those on which most work has been done, belong to J. B. Quigley, one of the original discoverers of placer gold in the district. A number of claims are owned jointly by Mr. Quigley and another partner, and several are held in which he has no interest. Most of the claims on Friday Creek are shown on Plate 5.

At the time of the writer's visit Mr. Quigley was confined in the hospital with an injured leg, which he had the misfortune to break when a rock fell from the roof of a tunnel where he was at work. Mr. Quigley would undoubtedly have been able to supply the writer with information that could not be obtained otherwise, although the careful and systematic way in which prospecting has been carried on makes examination of some claims comparatively easy.

Red Top claim.—Part of the ore shipped from the Friday Creek area was mined from the Red Top claim. This claim is near Friday Creek, at the west end of the ridge and a little higher than the gravel bench that borders Moose Creek. The mineralized area is a vein or series of veins in a shear zone having a general trend of about N. 60° E. and is traced for more than 500 feet by a tunnel, several shafts, and a number of open cuts. (See fig. 8.) The schist is decomposed and cut by quartz veins and in many places is stained with iron oxide. The original ore minerals probably consisted chiefly of galena and zinc blende carrying gold, but a number of minerals are present, some of which are the products of oxidation.

Some of these later formed minerals contain a large part of the valuable metals.

Numerous open cuts extend up the hill along the shear zone to a point about 200 feet higher than the tunnel and over 500 feet from its entrance. Several of them yielded shipping ore from the surface, and one about 100 feet higher than the tunnel was developed by a shaft more than 40 feet deep and a drift that produced a quantity of high-grade shipping ore.

The main tunnel on the ore body extends for 300 feet in a winding course along the shear zone. Short crosscuts were driven from it, and two shafts were sunk at a point nearly under the workings of the surface shaft. Most of the ore mined and shipped from this tunnel came from a vein that lay parallel to the tunnel, near its mouth and a few feet south of it. A shaft was sunk to a level 32 feet below the tunnel, and from this shaft the ore was taken out.

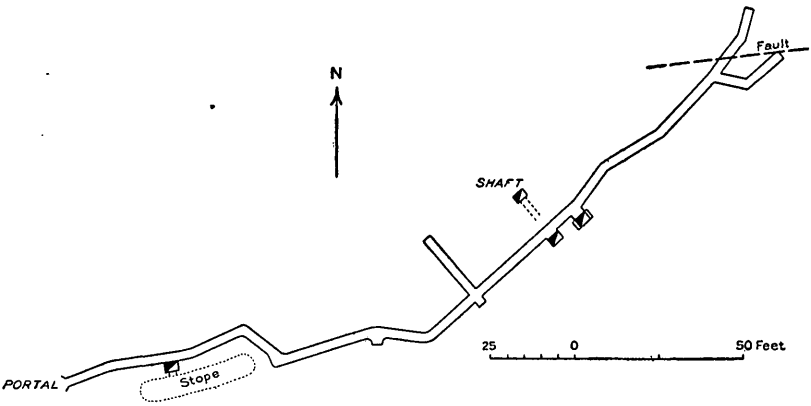


FIGURE 8.—Sketch map of tunnel and shafts on the Red Top claim

The variety of minerals found in the ore is greater than has been recognized elsewhere in the district and has interesting features. A list of the minerals identified was furnished to the writer by Mr. Paul Hopkins, of the United States Bureau of Mines, who is stationed at Fairbanks and for years has studied the ore from the Red Top claim and many other prospects in the Kantishna district. It includes galena, pyrargyrite (ruby silver), sphalerite, arsenopyrite, pyrite, probably marcasite, melanterite, free sulphur, scheelite, and scorodite. At one point sulphur is present in such quantity that it was recognized by the tunnel wall catching fire from a candle hung there. It is one of the secondary minerals, probably resulting from alteration of the iron sulphides.

The workings on this south vein are caved so that they were not examined, but the high grade of the ore at this part of the shear zone suggests either an original concentration of valuable minerals in the vein or enrichment resulting from oxidation. The tunnel beyond the south vein shows fairly uniform amounts of gold and silver but has not revealed high-grade silver ore like that which was mined.

The Red Top claim has produced approximately 100 tons of ore, valued at more than $250 a ton, which was shipped to the market. Of this quantity 38 tons was mined from the open cuts and shaft above the tunnel and the remainder from the south vein, except 6

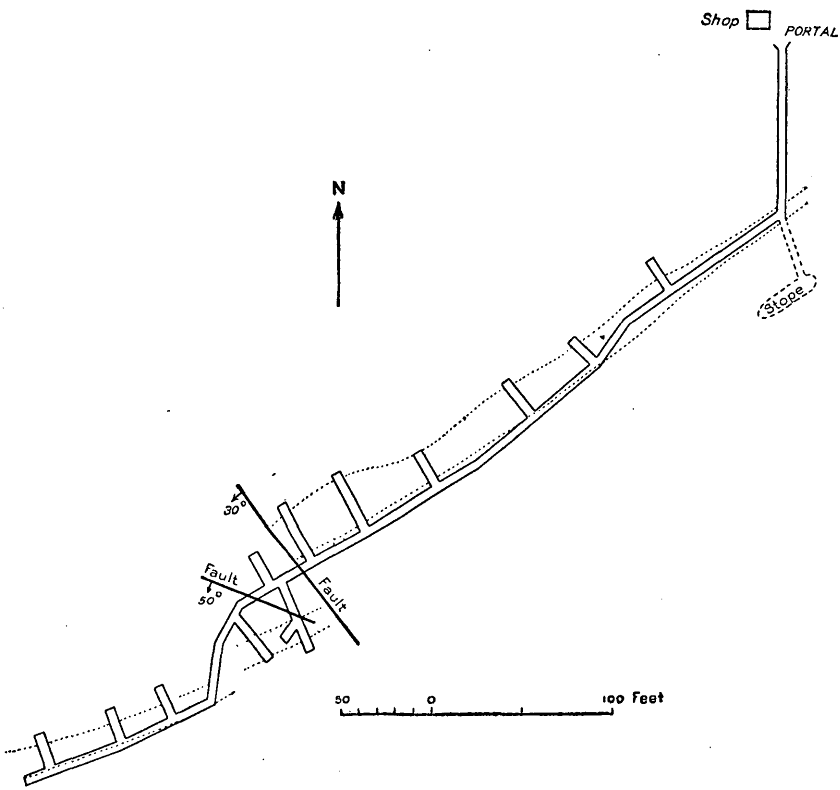


FIGURE 9.—Drift and crosscuts on the Little Annie claim. Position of old stope is approximate. Dotted lines show position of the vein

tons, which was obtained while driving the tunnel. The ore from the tunnel averaged 0.88 ounce of gold and 209.3 ounces of silver to the ton and 37.5 per cent of lead. The ore from the open cut and shaft had a higher value in gold, averaging 2.53 ounces to the ton. Fortunately for the owner this ore was mined between 1921 and 1925, when the value of silver was much higher than at present.

Little Annie claim.—The little Annie claim is east of the Red Top claim, on the Friday Creek side of the ridge. It has been prospected by open cuts and a tunnel 500 feet long (fig. 9) and has produced the largest amount of high-grade ore that was shipped to the smelter.

A road nearly a mile long extends from the camp on the Red Top claim to the tunnel on the Little Annie claim and beyond that point is continued as a trail that gradually rises to a low point on the ridge, crosses over to the Eureka Creek side, and leads to the Banjo claim, described on pages 330–331.

The country rock is a much crushed and weathered gray schist containing numerous stringers and lenses of quartz. Two veins of valuable minerals were encountered in the tunnel. The one on the north is a mineralized shear zone, ranging in width from 5 to 25 feet, containing gold accompanied by quartz. Its strike is about N. 55° E., and its dip is steep to the south. A long drift was run on this vein, and further exploration was carried on by cross cuts spaced at slightly irregular intervals but averaging about 50 feet apart. At the point where the vein was encountered in the adit tunnel its width is a little more than that of the drift, but the width increases southwestward along the drift and reaches a maximum at a distance of 300 feet. At 325 feet the vein is crossed by a fault, striking northwest and dipping 30° SW., and is offset approximately 40 feet to the southeast. A second fault 25 feet beyond strikes N. 70° W. and dips 50° S. The vein extends beyond the first fault and was followed by the drift 200 feet farther. The shear zone is made up of crushed banded quartz and country rock shattered into angular fragments and has the same course as the schistosity of the country rock. It contains a small quantity of disseminated pyrite and carries gold and a little silver.

The second vein lies about 50 feet south of the gold-quartz vein just described but could not be examined at the time of visit, as the crosscut leading to it was filled with ice and the surface opening was caved. This vein was mined in 1921 and produced 700 tons of high-grade silver ore averaging not less than $150 to the ton, a grade of the lowest value which could be mined profitably at that time. The valuable minerals were galena and tetrahedrite. The ore carried gold in addition to the silver and doubtless a certain quantity of zinc, although this is not regarded as of importance.

The silver-lead vein was explored from the surface by a shaft and the gold-quartz vein by a series of open cuts along the hill slope, which disclose its presence. It is thus shown that the mineralized part of the shear zone has a vertical dimension above the tunnel of over 100 feet. No work has yet been done to explore the vein below the level of the tunnel.

Gold Dollar and Golden Eagle claims.—The Gold Dollar and Golden Eagle claims are near the head of Friday Creek, adjoin each other end to end, and extend onto the divide between Friday and Eureka Creeks. These two claims have produced 600 tons of high-grade silver-lead ore, said to average more than $150 to the ton, which was shipped to the smelter. The workings on the claims are now caved and inaccessible. The tunnel of the Golden Eagle was driven on a shear zone that has the same trend as the schistosity of the country rock, N. 55° E., and dips 50° SE. According to Capps,[12] the vein, which had been discovered in an open cut at the time of his visit in 1916, was 3 feet wide. Of this width 2 feet was heavily mineralized with galena, pyrite, sphalerite, and copper carbonates and contained considerable free gold. The ore from the Gold Dollar, as stated by Mr. Quigley, consisted chiefly of galena and tetrahedrite but contained other high-silver minerals. Among the more unusual minerals determined by Mr. Hopkins are stephanite (a sulphide of silver and antimony), stromeyerite (sulphide of copper and silver), and bournonite (sulphide of lead, copper, and antimony). Zinc is also shown by the assays from the Gold Dollar and indicates the presence of sphalerite.

Silver Pick claim.—The Silver Pick claim lies higher on the ridge than the Little Annie, but the two have a common boundary for nearly one-quarter of their length. This claim was explored by open cuts and a tunnel. Two veins are exposed on the surface. The larger is a shear zone nearly 10 feet wide, made up of crushed quartz and schist and stained with light-colored oxides resulting from weathering. It strikes N. 35° E. and dips steeply northwest. A smaller vein is exposed by an open cut about 175 feet distant toward the southeast. A straight tunnel nearly 200 feet long was driven S. 30° E. to intercept these veins. The first vein was cut 55 feet from the entrance and prospected by a short drift run to the southwest. The mineralized part of the vein is 5 feet thick and composed of crushed rusty quartz containing galena. At the end of the tunnel is a second crushed zone parallel to the first but dipping southeast. This zone is wider than the first one encountered in the tunnel, but there is some question as to its being the second vein exposed on the surface. The metallic minerals consist of pyrite, arsenopyrite, galena, and sphalerite. Melanterite or iron sulphate results from the oxidation of the sulphides. A small amount of gold is present and the silver content increases as the quantity of galena increases. Samples of the galena containing nearly 300 ounces of silver to the ton have been assayed.

Banjo claim.—The Banjo claim is east of Friday Creek near the crest of the ridge between Eureka Creek and a tributary of Glacier Creek. It is a little more than 3 miles from the Camp on the Red

[12] Capps, S. R., The Kantishna district, Alaska: U. S. Geol. Survey Bull. 687, p. 104, 1919.

Top claim and is reached by the wagon road and trail previously mentioned. Its altitude is about 3,500 feet, or 2,000 feet above the mouth of Friday Creek.

The country rock consists of silvery siliceous schist and black graphitic schist containing quartz lenses and stringers. Near the crest of a low sag in the ridge a number of open cuts have been made on auriferous quartz veins in a shear zone having the trend of the schistosity. The largest exposure is a mass of iron-stained quartz containing free gold. The thickness and trend of this particular vein are not clearly evident. It is contorted and appears to be a large lens or irregular mass rather than a fissure vein. As much as $11 in gold has been obtained from a pan of the crushed quartz.

A tunnel was started on the side of the ridge toward Eureka Creek and about 100 feet lower than the crest, in order to cut the quartz veins at depth. This tunnel is in the black schist and was 60 feet underground at the time it was visited, but work on it was interrupted during the summer of 1930 because of the accident to Mr. Quigley.

Other claims.—Most of the claims on the Friday-Eureka Creek ridge are patented, and some have had little work done on them since the patents were issued. The old workings on many claims are no longer accessible, either because the loose material has slumped into the open cuts or because the underground tunnels and shafts are caved or filled with ice. The claims so far described are chiefly those which have produced ore or have had recent work done on them. There still remain a number that should be mentioned, either because they have produced ore or have promising showings and have had work done on them. Several of them were described by Capps, and little if anything can be added to his account.

The Galena claim is near Moose Creek, about halfway between Eureka and Friday Creeks. This claim is the property of Charles McGonogill. It has been prospected by open cuts and a tunnel that was not examined by the writer. The showing is a shear zone that strikes northeast and is mineralized with pyrite, arsenopyrite, galena, and sphalerite.

The Lucky Strike claim is on Moose Creek a short distance above Eureka Creek. A vertical quartz vein 6 to 8 feet thick strikes N. 45° E. and cuts the schist in the bluff on the east side of the creek. The quartz vein is fractured through faulting and is heavily stained with iron. It extends about 75 feet above the river and was prospected by a short tunnel 50 feet above the river. The tunnel, however, had caved and was inaccessible. Samples from the tunnel are reported to run more than $8 in gold to the ton.

The Pennsylvania and Keystone prospects lie end to end on the south side of the Friday-Eureka Creek ridge, below the point where the trail to the Banjo claim goes through the saddle, and are crossed near their common boundary by a small tributary of Eureka Creek called Iron Creek. They have been prospected on the surface by numerous open cuts and underground by a shaft and tunnel. The main showing, as seen in the surface exposures, is a crushed and iron-stained quartz vein 3 feet thick that strikes N. 50° E.

Several hundred feet of the vein was exposed by the open cuts. The metallic minerals are abundant in places and include arsenopyrite, sphalerite, and galena. Free gold may be distinguished with the eye and is obtained from the crushed rock by panning. Assays from the shaft on the Pennsylvania claim are reported to have yielded $30 in gold to the ton of ore. Very beautiful specimens of crystalline gold were taken from an open cut on the Pennsylvania claim in the early days. They were found in pockets in an oxidized quartz vein from 1 to 6 inches thick from which the original sulphide minerals had been dissolved and carried away, leaving the gold behind.

Among the remaining claims shown on the claim map several, including the Little Maude, Francis, and White Hawk, have produced ore or have high-grade showings. Two claims, the Whistler and Bright Light, on the west side of Moose Creek were not examined.

ELDORADO CREEK

Eldorado Creek is a southern tributary of Moose Creek and joins it near the mouth of Eureka Creek. In the early days of the camp a little placer mining was done on the stream, and somewhat later a small quantity of high-grade lead-silver ore was mined from a prospect on the mountain on the northwest. This ore was "rawhided" to the creek and hauled from there with sleds. No significant developments have taken place, and little work has been done on the creek in recent years.

The country rock is schist and includes considerable of the black graphitic type in addition to the lighter, more siliceous varieties. About 3 miles from the mouth of the creek is an area of light-gray coarse-grained granitic intrusive rocks, which include masses of the schist. Near the south margin of this area a tunnel 40 feet long was driven into a body of the included schist on the south side of the creek. A vein of crushed and rusty quartz at the contact of the schist and intrusive rock contains iron sulphides and galena and thus suggested driving the tunnel. About 100 feet higher on the hill to the south is an open cut in slide rock that contains a large quantity of coarsely crystalline galena, but the vein source was not in view. Another open cut 50 feet above the first exposes galena in a quartz vein. These exposures are not sufficient to give a clear idea of the extent of the mineralization, but the showing made by the float justified what has been done so far. A spring of cold sulphur water was noted near the creek a short distance below the tunnel.

GLEN AND SPRUCE CREEKS

Glen and Spruce Creeks are upper tributaries of Moose Creek. They are east of Friday Creek and drain the south slopes of Glacier and Spruce Peaks, two high peaks in the ridge between upper Moose Creek on the south and the headwaters of Glacier and Caribou Creeks on the north. This ridge, so far as is now known, is the chief area of gold mineralization in the Kantishna Hills, and the creeks draining it have yielded much the larger part of the placer gold in the district. Without doubt the placer gold was derived from the weathering of auriferous veins cutting the schists of the ridge. Several veins of this kind have been discovered and staked, but no one of them has yet been a producer of ore.

The Lena claim is near the top of the ridge east of the head of Spruce Creek. The country rock is a siliceous schist which is here cut by a quartz vein that strikes N. 60°–70° E. and dips steeply south. This strike is the same as that of the schistosity, but the dip is in the opposite direction to that of the schistosity, and the vein consequently cuts across the foliation of the schist. The vein here exposed in an open cut is 5 feet wide, and about one-third consists of high-grade galena ore. According to C. A. Trundy, United States commissioner of this district and owner of the property, a sample of the ore assayed half an ounce of gold to the ton and had a total value in gold, silver, and lead of $90 to the ton during the time of high prices for silver after the war. The vein may be traced up the hill for a short distance, but the galena content becomes less. Several smaller quartz veins striking with the schistosity are exposed near by on the top of the ridge at the head of Spruce Creek. They are reported to carry gold but have had little work done on them.

John Stendall has prospected a claim near the top of the ridge at the head of the east branch of Glen Creek. Several open cuts and a short tunnel, now caved, were made to explore a series of parallel veins of milky quartz, slightly iron stained and carrying free gold. The zone occupied by the five or six veins now exposed is nearly 50 feet wide, strikes N. 55° E., and dips steeply north. The quartz veins range in thickness from a few inches to 2 feet and have not been traced in the direction of their strike. Free gold is visible in specimens of the quartz.

A claim called Glen Ridge No. 1, the property of Mr. Trundy, is situated on the ridge east of the head of the west branch of Glen Creek. A massive vein of iron-stained white quartz occupies the top of the ridge. It strikes N. 65° W. and dips 30° SW., apparently conforming to the planes of schistosity of the country rock. The vein is from 20 to 30 feet thick and is exposed over at least half an acre of ground. A shaft about 10 feet deep was dug in the rusty crushed quartz on the north side of the exposure. The quartz is mineralized with iron sulphides and contains free gold.

Two tunnels have been driven on a quartz vein on the southeast side of Glacier Peak. The country rock is a blocky gray siliceous schist showing fine mica scales on the surface and a plane cleavage without crenulations. Both tunnels were caved at the entrance and partly filled with water, so that they could not be examined. The lower tunnel is 150 feet below the summit of a spur that projects southward. Specimens of ore from the dump show zinc blende, stibnite, and a little galena. Above this tunnel, on the same vein and 50 feet below the crest of the spur, is a second tunnel. The quartz vein continues west from this point across the low saddle and is easily traced by the float for about 300 feet. This claim is the property of Lee Swisher.

PLACER MINING

The Kantishna district was first known as a gold-placer camp and at the time of the discovery of the placers was the object of a spectacular stampede such as marked the beginnings of all the better-known Alaska camps after the discovery of gold on the Klondike, in the Yukon Territory. The following account of the early history of the district was given by Capps:[13]

> The discovery of gold in the Kantishna district was an indirect result of The Fairbanks rush. In 1904 Joe Dalton and his partner Reagan prospected in the basin of Toklet River and after having found gold in encouraging amounts returned to Fairbanks that fall. The next spring Dalton and another partner, Stiles, returned to the Toklat and prospected on Crooked Creek, a tributary heading in the Kantishna Hills 16 miles south of Mount Chitsia. In the summer of 1905 two other prospectors, Joe Quigley and his partner Jack Horn, had been told by some trappers that there was gold in Glacier Creek, and they came in to investigate. They found gold in paying quantities, staked the creek, and in June of that year carried the news of their discovery to Fairbanks and so started the stampede to Kantishna. The stampeders began to arrive at the scene of the discovery about July 15, 1905. Meanwhile Dalton and Stiles, having heard nothing of the Quigley-Horn discovery, had traveled along the southeast side of the Kantishna Hills and arrived at Friday Creek. Prospecting there they found gold, and on July 12 staked that stream. On July 20 they staked Discovery claim on Eureka Creek, but thinking themselves entirely alone in the country they staked only that claim, having determined to prospect first the upper part of the stream. They went up Eureka Creek, and on their way back to the mouth of that stream they met a man named Cook, who had come in with the rush and had made his way up Moose Creek

[13] Capps, S. R., The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 75–76, 1919.

to the mouth of Eureka Creek. Cook said he had staked claims No. 1 to No. 4 on the Eureka, so Dalton and Stiles returned and staked the rest of the creek above claim No. 4.

Late in the summer and in the fall of 1905 the Kantishna district was the scene of great excitement. Several thousand people then arrived, most of them coming by boat up Kantishna River and its tributaries, Bearpaw and McKinley Rivers, during the season of open water, and by dog and sled later in the fall after snow had fallen. Practically every creek that heads in the Kantishna Hills was staked from source to mouth, and the benches and intervening ridges were not ignored. Within a few weeks a number of towns were built, the largest of which were Glacier, on Bearpaw River at the mouth of Glacier Creek; Diamond, at the mouth of Moose Creek; Roosevelt and Square Deal, on Kantishna River. At each of these places log cabins, stores, hotels, and saloons were erected, and between them and the creeks a constant stream of gold seekers traveled back and forth. By midwinter, however, it became generally known that the rich, shallow diggings, the eternal hope of the prospector, were restricted to a few short creeks, and an exodus began. The richest ground was mined vigorously during the summer of 1906, but by fall the population had dwindled to about 50, those who remained being the few who had staked paying claims or who were convinced that thorough prospecting held out sufficient promise of new discoveries.

Since the district was visited by Capps in 1925 the gold placer situation has changed little. No new sources of gold have been found, and the production of the district has gradually diminished. The producing creeks were described by Capps at the time when mining was in progress on them, and the conditions for examining the deposits were better then than now. A detailed account of them is given in his report and need not be repeated here.

The total production of placer gold in the Kantishna district during the 26 years from 1905 to 1930 is estimated to be about $500,000. At present most of the gold comes from Eureka Creek, but Glen, Little Moose, and Glacier Creeks yield a few hundred dollars additional each year. All the mining is done by simple methods which involve primarily the use of an automatic dam for sluicing away the shallow overburden. The remaining gravel and as much of the bedrock as is necessary is shoveled into sluice boxes by hand after the boulders have been piled out of the way. Some of the large boulders are broken with powder, but this procedure is avoided when possible because the high cost of powder at this distance from the market makes its use too expensive. The season of 1930 was not favorable for placer mining, because a late spring was followed by lack of water for operating the boomers. No shoveling into the boxes was done on Eureka Creek till about the 1st of July.

A hydraulic plant with a ditch and pipe line was installed on the west side of Moose Creek opposite the mouth of Eureka Creek in the early days, but the venture was not profitable, and the plant has not been in operation for several years. No other venture involving so large a capital outlay has been undertaken since that time.

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COAL

The district under consideration is not known to contain extensive areas of coal-bearing rocks, although several small areas are present. The largest deposit of such beds is a long, narrow synclinal basin occupying the valleys of the extreme southeastern tributary of Moose Creek and the tributary of Stony Creek which heads against it. Other small areas of the coal-bearing rocks are known on Boundary Creek, Clearwater Fork of the Toklat River, Glacier Creek, and the head of Coal Creek, one of the tributaries of Clearwater Creek (tributary to the McKinley Fork). It is probable that other areas of coal-bearing beds are concealed by the gravel deposits and that they may be more extensive than is now known.

The Moose Creek-Stony Creek area appears to be the most promising as a possible source of fuel for local use. The coal-bearing rocks in the lowest part of the valley include an alternating series of clay, sand, and gravel and streaks of impure carbonaceous material. The coal-bearing beds on the north side of the basin dip steeply south and here include 12 feet of weathered lignite associated with purple shale and a mass of intruded andesite porphyry. This bed of lignite has furnished some fuel for local use. The lignite was hauled to Mount Eielson and burned as fuel when development work was carried on there, and doubtless the field could supply a much greater quantity, although the extent of the coal bed is not known. A little coal was mined in the Boundary Creek area, and it appears probable that prospecting might reveal a coal bed in the gulch near Muldrow Glacier, where the trail from Thorofare Pass ascends the bench south of Moose Creek, for abundant fragments of float coal are present there.

Beds of lignite occur on both forks of Coal Creek but have not been prospected enough to determine their extent, although pits on the west branch of the creek indicate that a lignite bed of considerable size is present. These deposits probably have no value except for use in the immediate vicinity. Any need for fuel along the park highway could probably be met more cheaply with coal from better sources where the coal is present in greater quantity, as it is in several places between Muldrow Glacier and the Teklanika River. The series of passes leading eastward from Muldrow Glacier appears to be due to the weathering away of soft beds of the coal-bearing group that were infolded in the older sediments. These beds have not been entirely removed, and the soft sand and shale accompanied by lignite are present on the East Fork of the Toklat, in Polychrome Pass, Highway Pass, and Thorofare Pass. More extensive lignite beds are present on the Teklanika, Sanctuary, and

Savage Rivers just within the north boundary of the park and at Healy, east of the Nenana River, where coal is mined commercially.

CONCLUSIONS

The Kantishna district is a mineralized area that has produced nearly $500,000 in placer gold and over $200,000 in high-grade lead-silver-zinc ores during the last 25 years. These metals are derived from or occur in metamorphosed sedimentary beds that have been intruded by acidic igneous rocks, and they are believed to owe their deposition in the sedimentary beds to processes which were part of this intrusion. The silver-lead-zinc ores in particular are the result of the invasion of calcareous beds by the metal-bearing solutions or gases which accompanied the intrusive rocks and are therefore more likely to be found where intrusion of such beds has taken place. Aside from the gold placers the silver-lead-zinc ores, together with the gold-bearing quartz veins and deposits of stibnite, are the metalliferous deposits that so far have received most attention from prospectors. Gold-bearing quartz veins and silver-lead-zinc deposits are associated with each other in several places, yet it appears probable to the writer that they belong to different periods of mineralization. Although the lead-silver-zinc ores have been mined to some extent and gold-bearing quartz veins of considerable size have been blocked out by extensive drifts and crosscuts, no producing mine is in operation or seems likely to be brought into operation till further exploratory work has been done and more favorable conditions for mining have been established.

Development of the district has been hindered from the beginning by the lack of adequate transportation and the high cost of labor and supplies. When first discovered, the placer deposits of the Kantishna Hills gave promise of another bonanza gold field, but the gold-bearing gravel proved to be of small extent and the richest deposits were soon mined out, so that the gold production of later years has been comparatively small and constantly diminishing. The silver-lead ores were mined when the price of silver was high, yet in spite of this favorable condition the cost of mining and transportation was so great that only the richest of the ores could be shipped with profit, and consequently the lower-grade ores were rejected, for no concentrating processes were used. At one time a temporary increase in the value of antimony resulting from the extraordinary war needs aroused interest in the stibnite deposits of Stampede Creek and elsewhere and led to the preparation of some high-grade stibnite ore for the market. None of this ore was shipped, however, for the unusual demand was temporary, and the price soon fell. No attempt has yet been made to develop any prospect in this district for its copper content. The Kantishna district at present is under the additional disadvantage that the prices for silver, lead, and zinc are remarkably low and give little incentive for the development of ore bodies whose value is dependent on them.

To offset some of the unfavorable conditions previously mentioned, the work which has been done so far has by no means exhausted the possibilities for the discovery of more ore in prospects already partly explored or for the discovery of other deposits not now known. The areal extent of the mineralization and the character of the known deposits justify the faith of those who have done most in the exploration of the district that profitable mining is possible within it.

MINING DEVELOPMENT IN THE TATLANIKA AND TOTATLANIKA BASINS

By Fred H. Moffit

ABSTRACT

The Tatlanika and Totatlanika Rivers rise on the north side of the Alaska Range east of the Nenana River and flow northward to the Tanana River. In early days their headwater tributaries were regarded as a part of the Bonnifield placer-mining district, but because of the increased importance of coal production from the Healy River and the diminished output of gold, the upper tributaries of the Totatlanika, if not of the Tatlanika, may more properly be considered as a part of the Nenana coal field.

This district has produced a small amount of placer gold each year since its discovery in 1903. In 1930 about 20 men were engaged in placer mining on different creeks within the area, but as much of the work was dead work in preparation for mining in the following year and a shortage of water for sluicing developed, the season was a disappointment to most of the operators.

Several lode gold prospects have been found in the district. One of much promise is being opened up on Eva Creek, about 10 miles from Ferry, on the Alaska Railroad, from which a good wagon road constructed by the Alaska Road Commission leads to the mine. The ore consists of gold-bearing sulphides—arsenopyrite, pyrite, and chalcopyrite—in schist which is probably derived from sedimentary rocks but is cut by granular intrusives. The ore body is being opened by a series of exploratory tunnels and raises, and the plans for exploitation include the building of a mill in 1931.

INTRODUCTION

The placer mining district lying east of the Nenana River and including the northern foothills of the Alaska Range between the headwaters of the Totatlanika and Wood Rivers, tributaries of the Tanana, has long been known as the Bonnifield district (see pl. 4), and although the western part of this district, including Healy Creek and the coal-bearing area to the north, is called the Nenana coal field and includes one of the principal coal-producing areas of Alaska, the following descriptions deal only with gold lode and placer mining.

The annual placer production of the district was never large, and in 1930 mining was carried on under unfavorable weather conditions, for the early part of the season was dry, producing a shortage of water for sluicing, and the late summer brought floods. At present a gold lode prospect on Eva Creek is under development, and another on Little Moose Creek is reported to have had work done on it. About 25 men were engaged in various mining enterprises in the district in 1930.

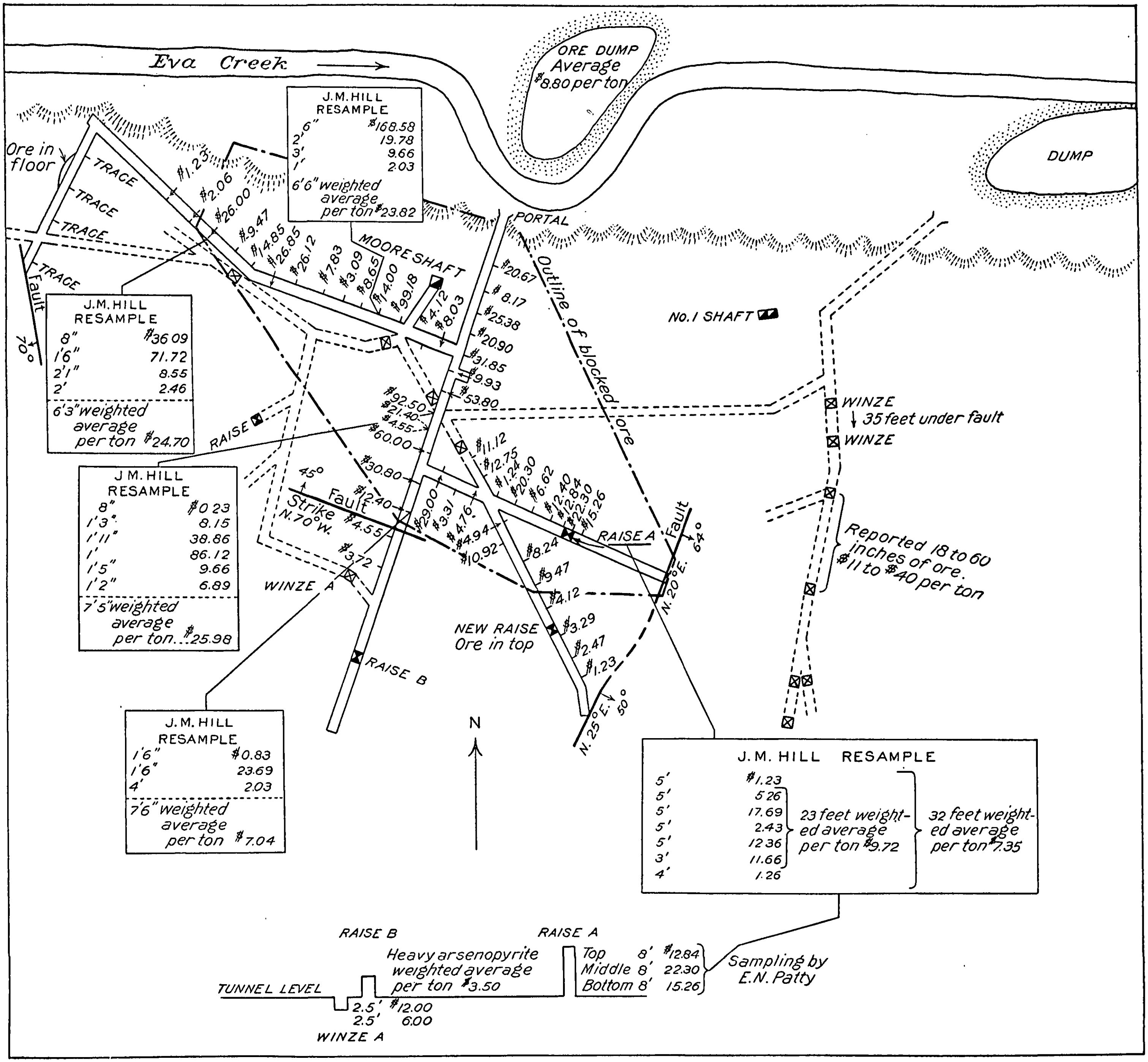
In the early days of mining in the Bonnifield district Fairbanks was the point of distribution for supplies, and the district was reached by trail directly from the Tanana River. In the last year or two a growing tendency to make Ferry, on the Alaska Railroad, the point of entry, even for the most distant points on the Wood River and Tatlanika Creek, has been evident. A wagon road 11 miles long was constructed several years ago by the Alaska Road Commission from Ferry, on the east side of the Nenana River at the railroad crossing, to the lode prospect near the head of Eva Creek. This road was never completed, owing to the temporary suspension of mining developments. However, even in its present state it is usable, except for short stretches during wet weather, and has been a great benefit to the men who have resumed operations on Eva Creek and to those who are interested in placer mining on creeks to the east.

EVA CREEK

A group of gold lode claims including several fractions has been located on Eva Creek 3 miles from its head. The claims (fig. 10) cover ground which lies chiefly on the south side of Eva Creek, and most of the development work done on them is near the creek level.

The country rock is schist of several aspects, including silvery-white siliceous schist with good cleavage, soft gray schist, and dark graphitic schist. These rocks appear to be altered sedimentary beds that probably include some calcareous members, and although they are much changed by recrystallization and the development of cleavage, the beds are not closely folded at this place but the cleavage is contorted locally. Strikes of the bedding range from N. 15° W. to N. 15° E., and the highest dip observed was 45°. The schist is cut by faults and is much-sheared and decomposed, so that it caves badly in the tunnels and makes timbering necessary. At one point on the Irene claim the dump from a tunnel shows a sheared and much altered rock of light color that suggests a metamorphosed granite or related igneous rock.

The rusty color of the weathered schist is due to the iron sulphide disseminated through it. In places the mineralization has been intense, and the chief sulphide is arsenopyrite, which is associated with a little pyrite, chalcopyrite, and bismuthinite. Free gold is present. Gangue minerals are inconspicuous, though quartz accompanies the sulphides and in places forms aggregates of long, slender crystals with sulphide minerals filling the spaces between them.



ASSAY MAP OF LIBERTY BELL MINE

More commonly the quartz occurs in the foliation of the schist. Relatively it is not abundant, so that the ore appears to consist chiefly of metallic sulphides and a varying proportion of the schist country rock. The sulphides appear as lenses and stringers in the foliation of the schist and have the same form as the quartz stringers and lenses common to contorted schist. They range in thickness from a fraction of an inch to nearly a foot. Some of the beds appear to have been favorable for deposition of the sulphides, whereas others show no such characteristics. No veins of sulphides cutting the beds were observed, and it appears that the problem of prospecting

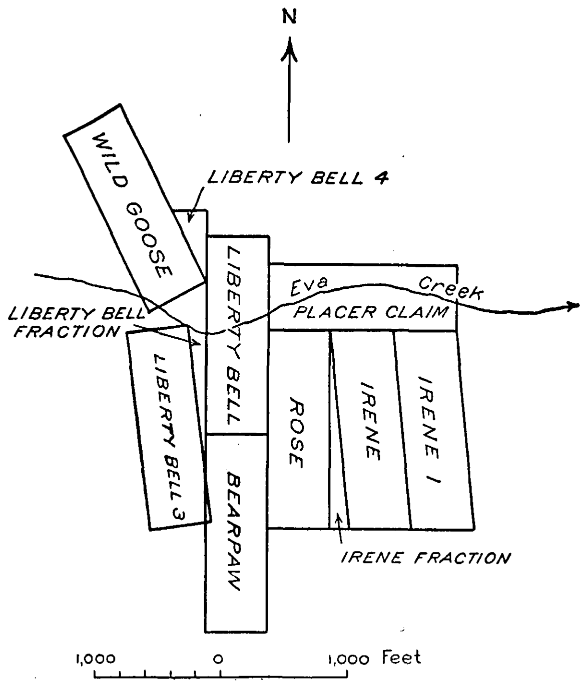


FIGURE 10.—Sketch map of claims on Eva Creek

and development is one of following favorable beds of the schist rather than of developing veins that cross the beds. The proportion of bismuth sulphide is small. It occurs in bright lead-gray elongated crystals filling the spaces between crystals of arsenopyrite and quartz. Gold is the metal of chief value in the ore. It is most abundant in the arsenopyrite, as is shown by the assays, but is seen as free gold in a good many specimens of decomposed rock picked from the dumps. Silver is present only in small amount, and the value of other minerals is negligible unless the bismuthinite has value.

This mineralized area was discovered in 1915 by two prospectors, Messrs. Swanson and Montaine, who did some work on it and then disposed of their interests to others, who continued the development work. The principal openings made prior to 1930 include a tunnel, said to be 60 to 70 feet long, on the Irene claim, three tunnels and a shaft on the Rose, and a shaft and tunnel on the Liberty Bell. Development work was suspended for several years because of a disagreement between different persons interested in the property and was not resumed till the present lessors, Justus Johnson, Bror Johnson, Al. Norberg, and Oscar Ericson, took hold of it and began prospecting the Liberty Bell claim in March, 1930. Most of the old workings on this claim were inaccessible in August, 1930, but they probably include as much as 800 feet of tunnel in addition to shafts and raises. A new adit was started in 1930, and approximately 300 feet of new tunnel had been driven at the time of visit by the writer. At that time the plans for future development of the property contemplated the construction of a small mill at the mine during the summer of 1931 if the development work in progress justified that expenditure. During the winter of 1930–31 it was planned to open up a coal claim of 10 acres, which had been staked on California Creek, and to haul fuel for future operations from that place by tractor.

This property is favorably situated with reference to railroad transportation, as the distance to Ferry is only 11 miles. Moreover, the wagon road can be put in good condition at comparatively small cost, and the grades are not heavy. So far as is now known the property presents no unusual mining problems that require solution. It was stated that the flow of water in Eva Creek is sufficient for mill use. On the other hand, the grade of Eva Creek will make the disposal of waste material increasingly expensive as mining continues. The property is above timber line, so that timber for mining will have to be hauled from the Nenana Valley.

In the summer of 1931 James M. Hill, of the United States Geological Survey, who had been studying the ore deposits of the Fairbanks district, was sent to the Liberty Bell mine of the Eva Creek Mining Co. to re-examine and sample the ore body. The following notes are based on data gathered by him during his visit and furnish additional information as to the character of the ore body, its geologic occurrence, and the progress of mining development.

The Eva Mining Co. was organized in Fairbanks during the summer of 1931 to take over the lease of the Johnson Brothers, Norberg, and Erickson on the Liberty Bell mine. Most of the stock issue was subscribed locally, and $40,000 was raised to put up a 50-ton flotation mill at the mine. The Alaska Road Commission had undertaken to complete graveling and grading of the 11-mile road from Ferry, on the Alaska Railroad, to the mine. During the winter of 1930–31 the lessees had driven about 800 feet of tunnel and put in several raises and winzes to check the work done by previous lessees in the main ore zone.

The previous work had been examined and sampled by Earl Pilgrim, of Fairbanks, and the Norberg-Johnson-Erickson work was examined and sampled by E. N. Patty, of the Alaska Agricultural College and School of Mines. In other words, much of this ore zone had been well opened and carefully sampled before any steps were taken to finance mill construction. Patty's detailed report was summarized as follows in the prospectus issued by the company.

The Liberty Bell mine is located in the Bonnifield mining district of interior Alaska, 11 miles by gravel road from Ferry station on the Alaska Railroad. Since June, 1930, it has been continuously under development by partners working under a 5-year lease and option. The lease calls for a 15 per cent royalty on gross returns from the ore marketed, and royalty payments apply on the purchase price of $115,000.

The ore occurs as a gold-bearing arsenopyrite replacing a flat-lying bed of soft schist. The commercial thickness of this relatively flat ore bed varies from 6 to 30 feet. Only limited exploration work has been done. This shows the following tonnage:

Proved ore	25,000 tons, average assay $22 per ton.
Probable ore	12,000 tons, average assay $22 per ton.

Prospective ore: Contiguous area barely prospected. Chance for additional tonnage promising.

Mr. Hill, in the course of his investigation, found outcrops of igneous rocks lying 900 feet southwest of the main tunnel on two low knobs and what appears to be a very much altered dike rock of similar type at the mouth of a prospect tunnel about 600 feet east of the main working tunnel. The relatively fresh rock on the knob southwest of the mine is a fine-grained granitic porphyry stained red by iron oxide and containing a little finely disseminated sulphide that appears to be arsenopyrite. Between the schist to the north and the granite porphyry there is a knob of hard, dense black rock that carries a much larger proportion of sulphide than the main mass of the intrusive. This rock is composed almost entirely of hornblende and is probably a marginal phase of the granitic intrusive. There is a small dike of granitic intrusive shown in the wagon road about 500 feet west of the mess house and also in a shallow caved shaft about 250 feet northwest of the mess house. The trend of this dike is N. 70° E., about parallel to the trend of the dike on the south of the ore body.

The schists in the ore body broadly lie nearly horizontal, but in detail are much disturbed, dipping as much as 28° either southeast or northwest. They are so fully sericitized, altered, and crushed in the ore body that their original composition is uncertain. Overlying the ore zone are thinly banded silvery white schists that break in thin plates, which are locally called quartzites. Between the "quartzite" and ore-body schists there is a zone of intense crushing and shearing with 1 foot to 3 feet of gouge. This appears to be a wavy, rather flat fault over most of the developed ore body, but at the ends of the two southeast drifts it strikes N. 20°–25° E. and dips 50° SW. (See pl. 6.) The ore developed under this fault plane does not go directly up to the fault. Replacement of the schist by sulphides seems to have been localized a few feet below the fault along lenticular planes parallel to the schistosity, though there is clear evidence that part of the solutions came up along nearly vertical fissures. At the south end of the main tunnel these vein forms are most conspicuous south of raise B.

The ore as developed is essentially a wavy nearly flat-lying replacement body with lenses of nearly pure sulphide half an inch to 18 inches thick. The intervening schist is bleached and softened and contains more or less disseminated sulphides. In a few places the replacement product parallel to the schistosity is a mixture of quartz and sulphide, though this type is not common. The whole ore body is soft and broken by many planes of movement, most of which are parallel to the schistosity but some of which cut sharply across the general structure.

The principal metallic minerals are pyrite and arsenopyrite, the latter by far the most abundant sulphide present. The sulphides have been oxidized to a certain extent throughout the workings, and the greenish-white arsenic oxide scorodite was noted scattered throughout the schist and as coatings as much as a quarter of an inch thick surrounding massive arsenopyrite. Polished sections of the solid appearing arsenopyrite show this material to be a mixture of arsenopyrite ($FeAsS$) and löllingite ($FeAs_2$) rather than a single mineral. There is also a little chalcopyrite and pyrite. Minute crystals and blebs of gold accompanied by quartz are seen in veinlets and irregular masses throughout the sulphide, being clearly later than the sulphide.

Prospecting has shown that there is some mineralization of the schists outside of the area blocked as ore by the present mine workings. There is a suggestion that the fault which overlies the ore body may turn down along the igneous intrusive. Possibly ore having a steeper dip will be found south of the present known ore bodies. No work has been done to indicate that these suggestions are or are not true, but they are based on the geologic relations.

Mr. Hill resampled certain places which had been sampled previously by Mr. Patty. The results of both samplings are shown on Plate 6 and are as closely in accord as could be expected in sampling ore deposits of this type. Mr. Hill's samples show that the higher gold tenor is found in the more highly siliceous sulphide ore lenses but that all of the schist carries gold. They indicate that it will probably be advisable to do some sorting of the hard massive sulphide ore, which will break in large blocks, as compared with the soft altered schist. The results of the examination would indicate that the estimates of ore reserves made by Mr. Patty are conservative.

PLACER MINING

Approximately 20 men were engaged during 1930 in placer mining or preparation for placer mining on streams between the Nenana and Wood Rivers and tributary either to these streams or to the Tatlanika and Totatlanika Rivers. The season was disappointing to most of the operators, however, because of the lack of water, and work was stopped on several creeks about the first of August.

Three men were at work on two properties on McAdams Creek, a small eastern tributary of California Creek 14 miles east of Ferry. Two of these men were doing dead work in preparation for the season of 1931.

One man was mining on Marguerite Creek, another tributary of California Creek, but was obliged to stop about August 1.

Seven men were at work on the Totatlanika River at the mouth of Fourth of July Creek. A hydraulic outfit, including a pipe line and ditch, was installed, but no piping had been done by the middle of August. Whether or not this plant was damaged by the flood waters of the later part of August was not learned by the writer. Supplies for this project were hauled by wagon from Ferry over a road between California Creek and the Totatlanika River, which has had no work done on it other than to cut the timber where that was necessary, and which was probably impassable in late August and September on account of the heavy rains.

Placer mining was done on Grubstake and Moose Creeks, eastern tributaries of the Tatlanika, and on Gold King Creek, a tributary of the Wood River. The hydraulic plant on Gold King Creek, known locally as the "old Berry property," was another of the plants that were shut down early in the season because of the water shortage.

Estimates of the total gold production of this district are difficult to make because most of the miners had left before the writer visited it, but it is doubtful, in view of the dead work being done and the unfavorable season, if the district as a whole paid wages in 1930.